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(54) **METHOD FOR MANUFACTURING THERMALLY-ASSISTED MAGNETIC RECORDING HEAD BY SEMI-ACTIVE ALIGNMENT**

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G11B 11/12 (2006.01)

(52) **U.S. Cl.**
USPC ... **29/603.1**; 29/603.2; 29/603.22; 369/13.11; 369/13.13; 369/13.24

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See application file for complete search history.

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(74) *Attorney, Agent, or Firm* — Oliff & Berridge, PLC

(57) **ABSTRACT**

A method for manufacturing a thermally-assisted magnetic recording head is provided, in which joined are: a light source unit that includes a light source having a surface including a light-emission center on the joining surface side of a unit substrate; and a slider that includes an optical system having a light-receiving end surface reaching a back surface opposite to the opposed-to-medium surface. This method utilizes "semi-active alignment" that uses an alignment light, and comprises steps of: causing a light to enter the light source from a surface opposite to the light-emission center; detecting the light that has passed through the light source and is emitted from the light-emission center to align the light-emission center with the light-receiving end surface of the slider; and bonding the light source unit to the slider. This manufacturing method can achieve the alignment with a sufficiently high alignment accuracy in a short processing time.

8 Claims, 9 Drawing Sheets

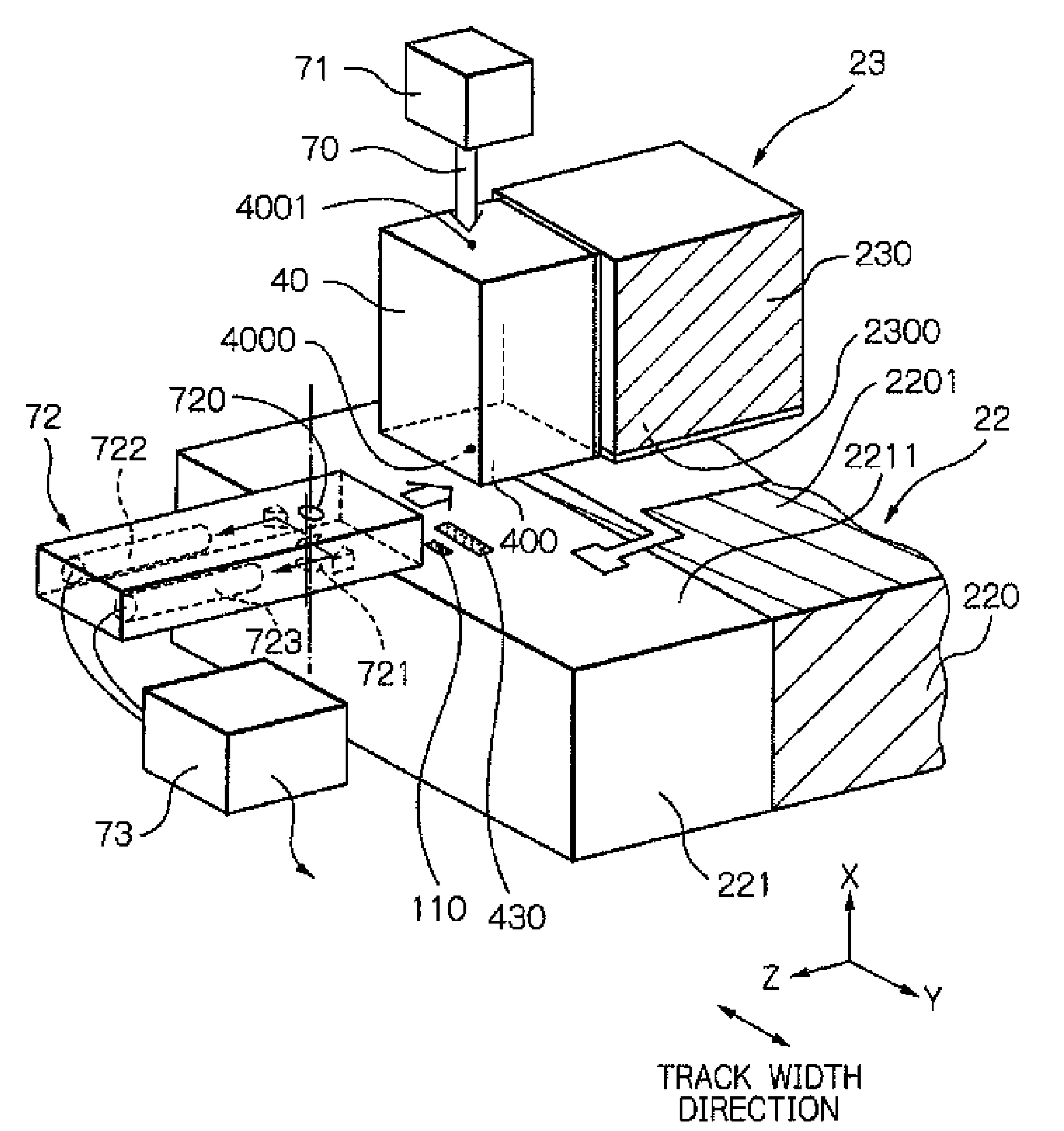

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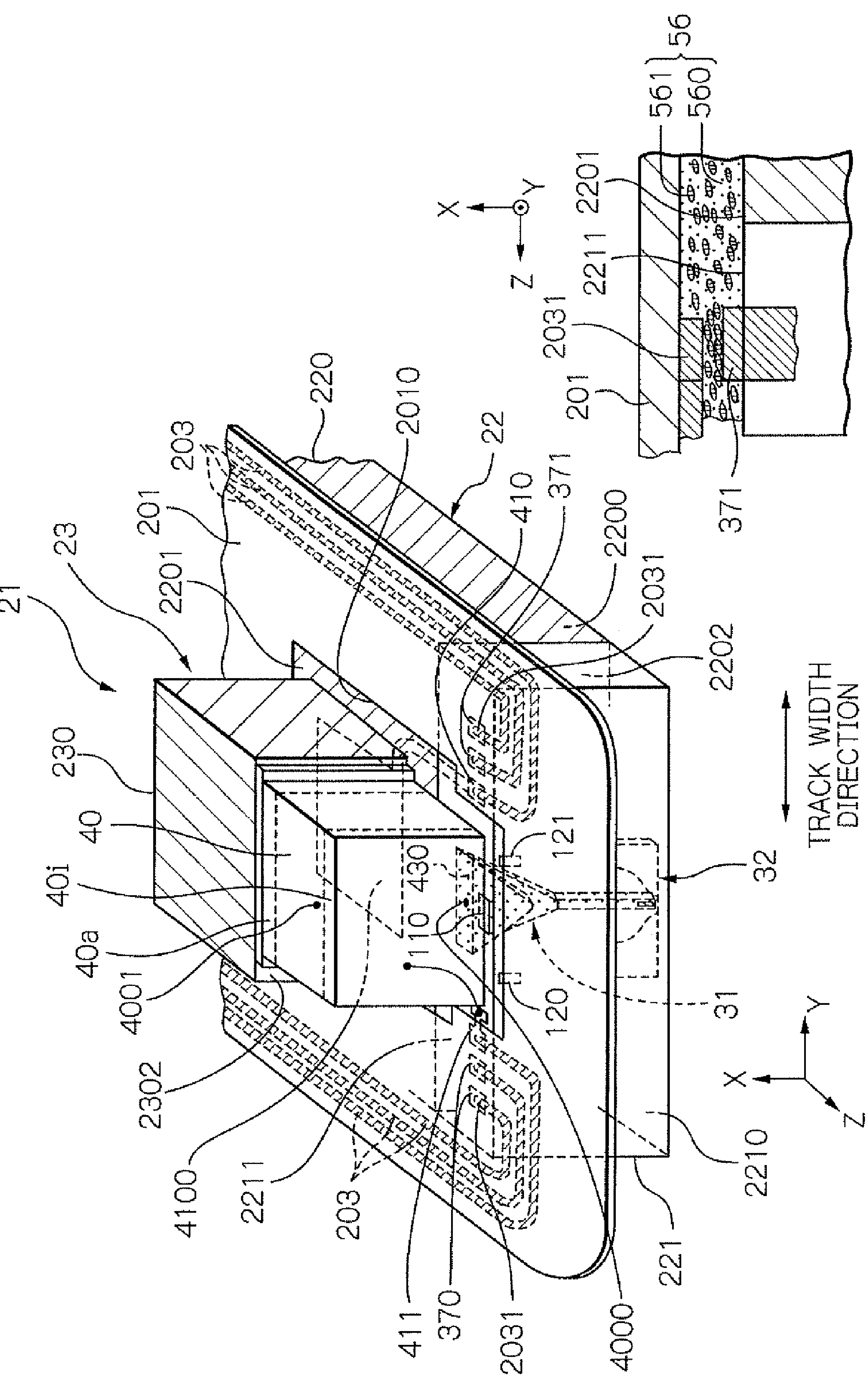
Fig. 1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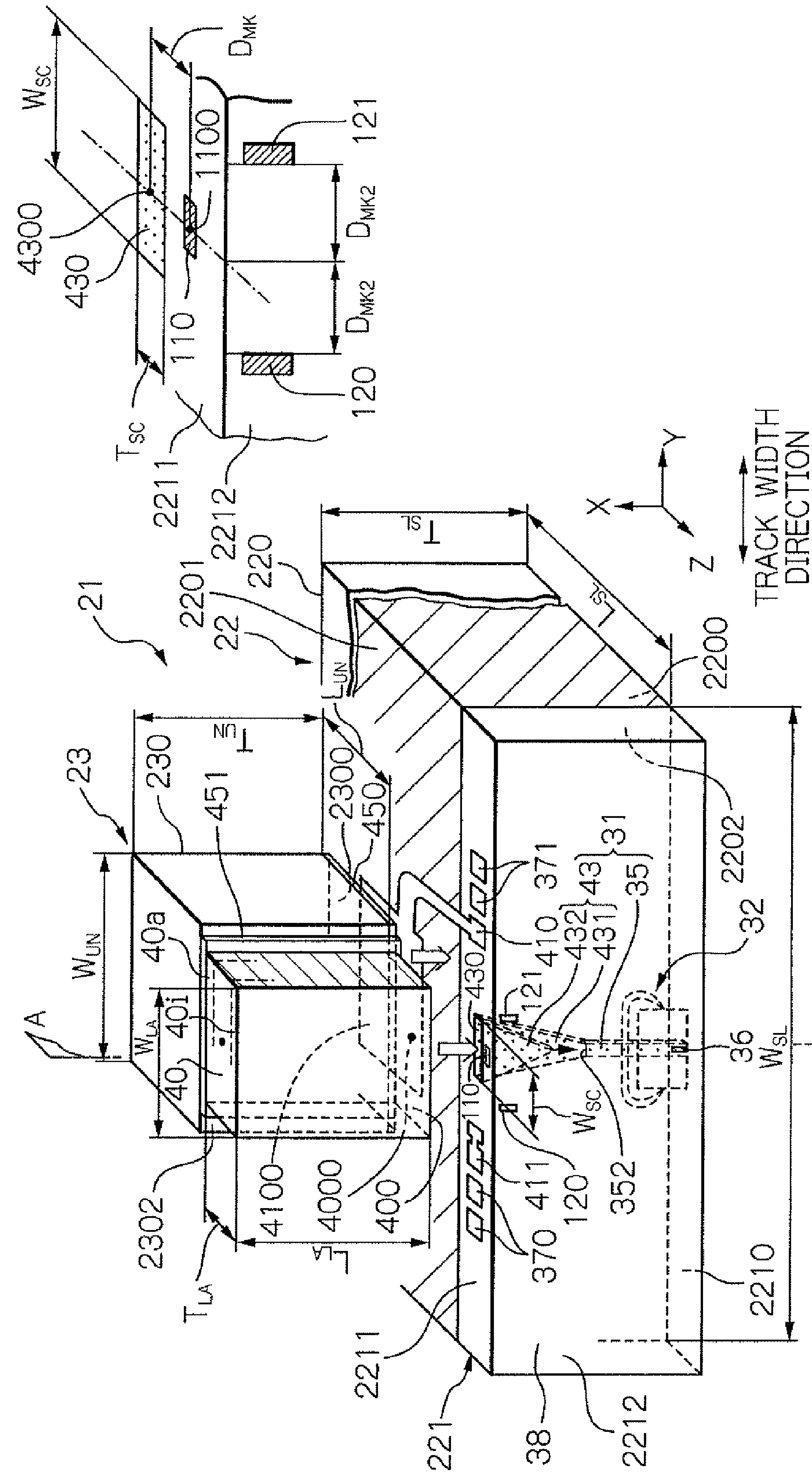
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Fig. 2

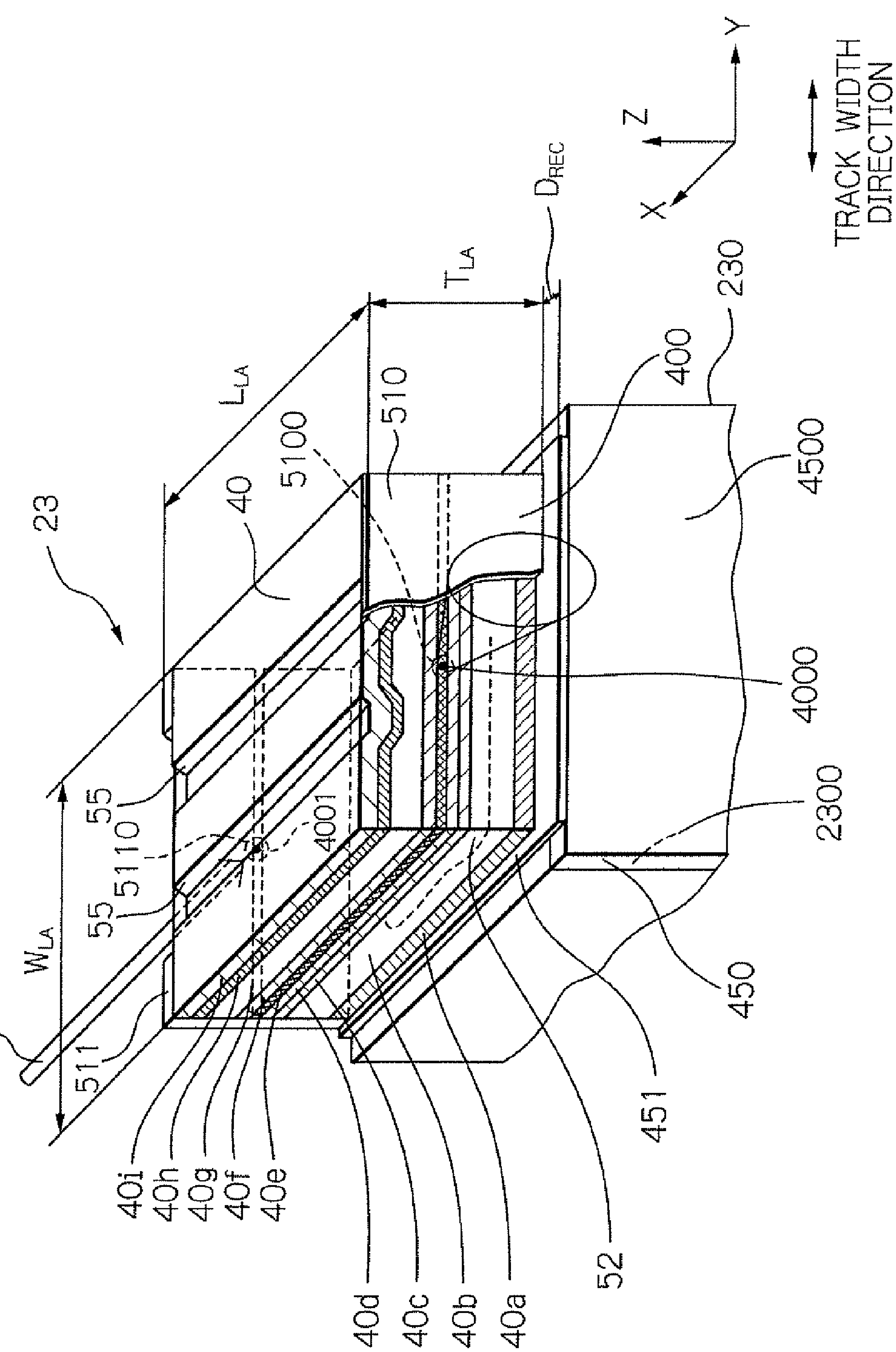

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Fig. 3

Fig. 4

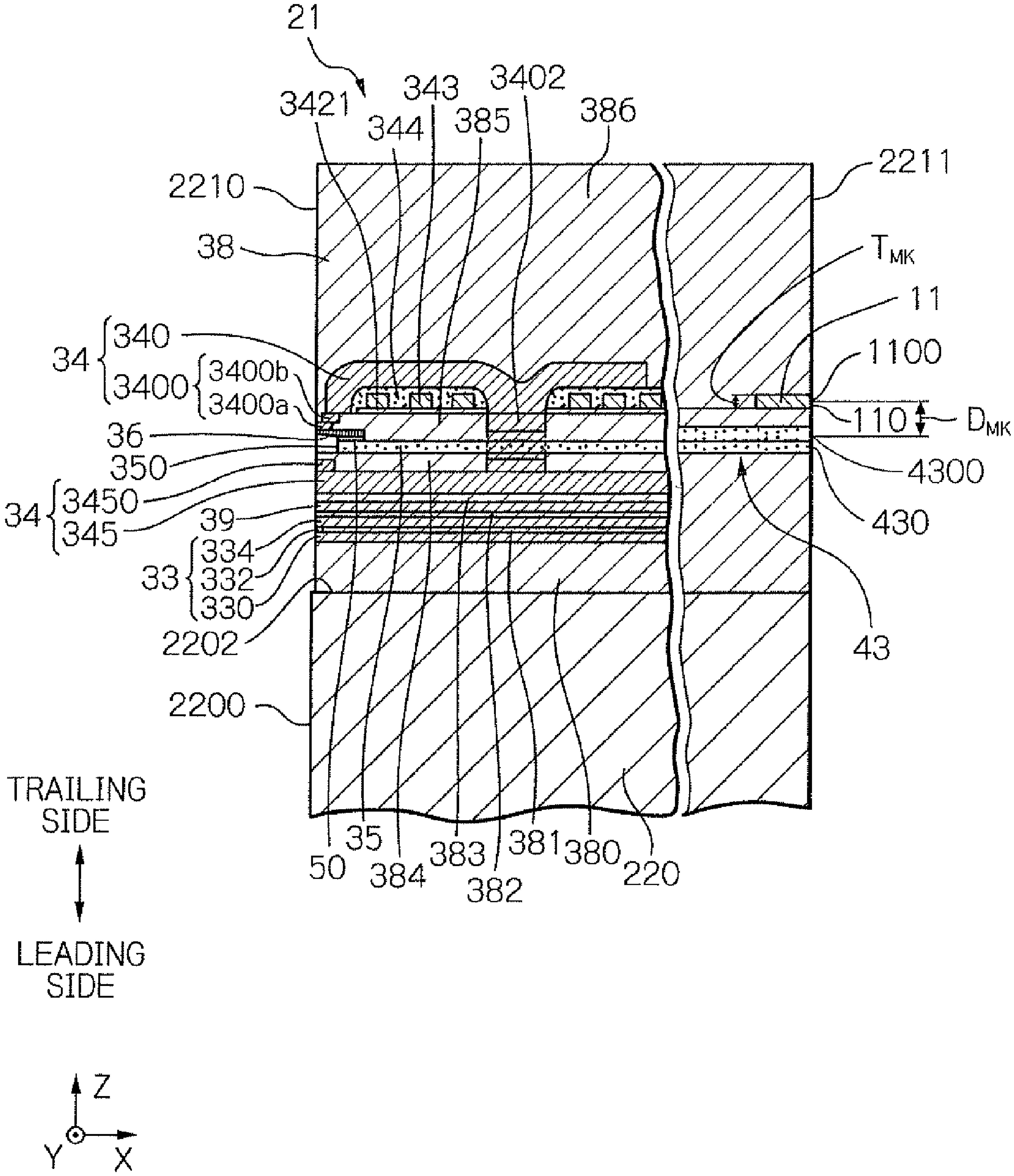
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Fig. 5

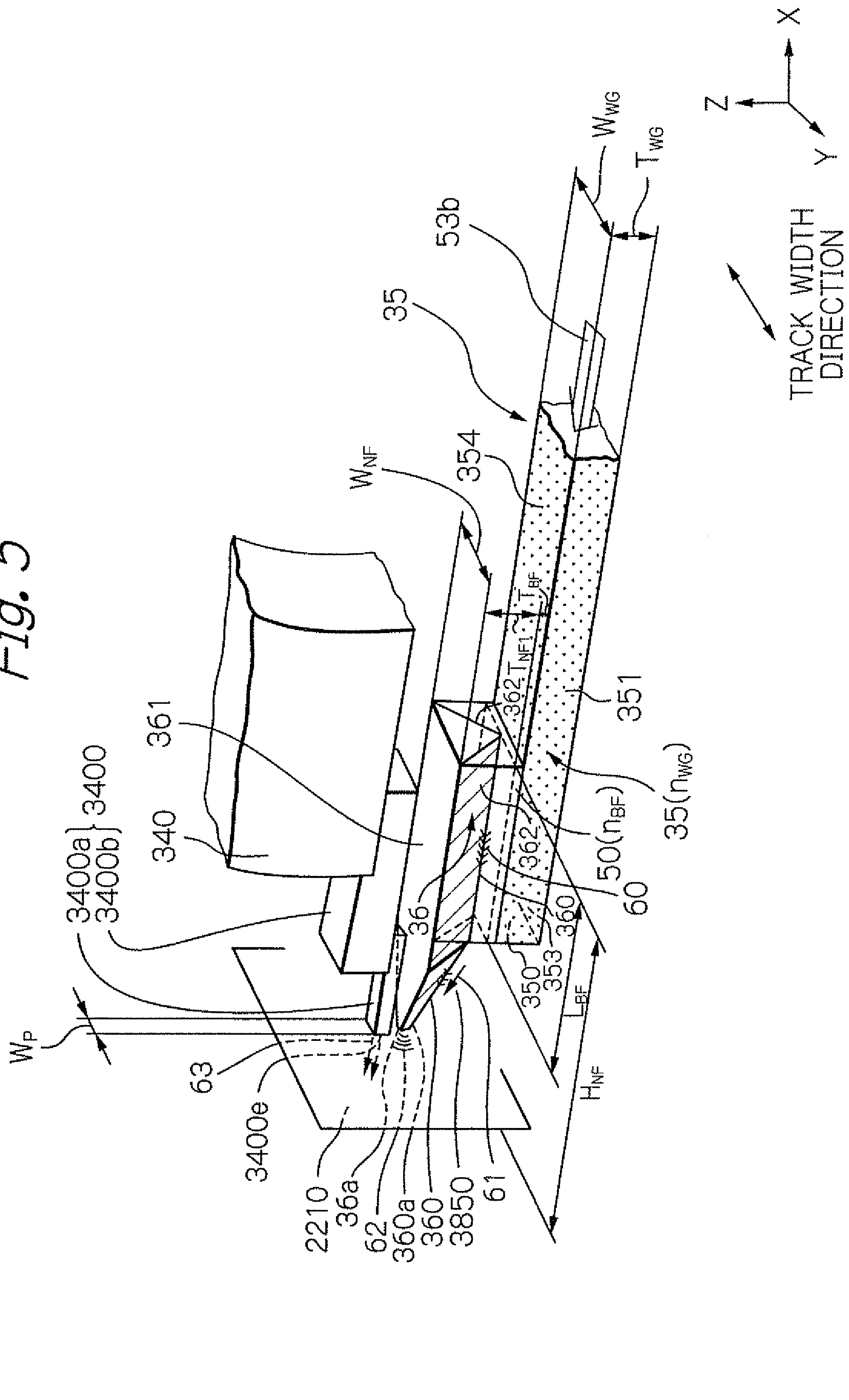

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Fig. 6a

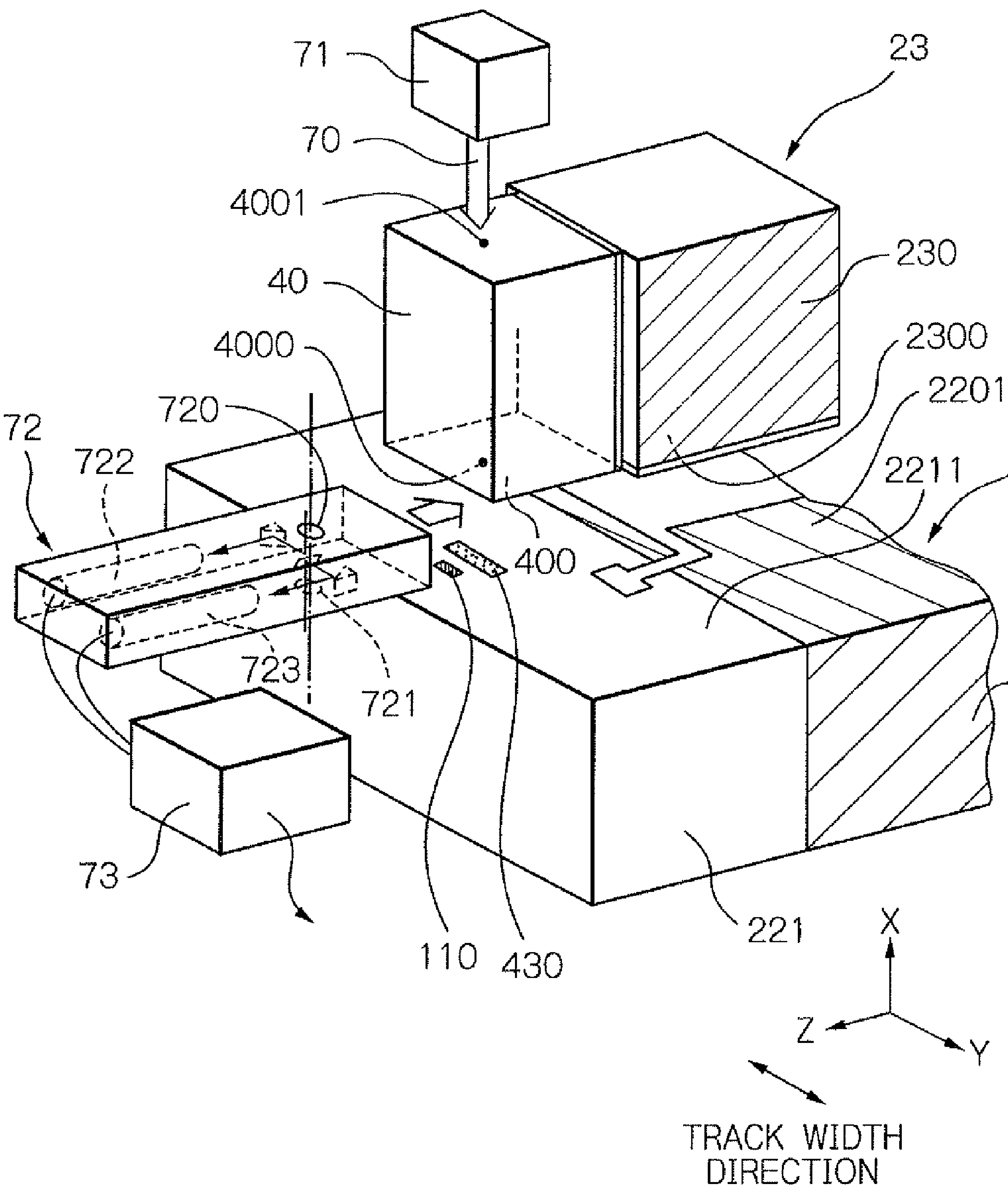
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Fig. 6b1

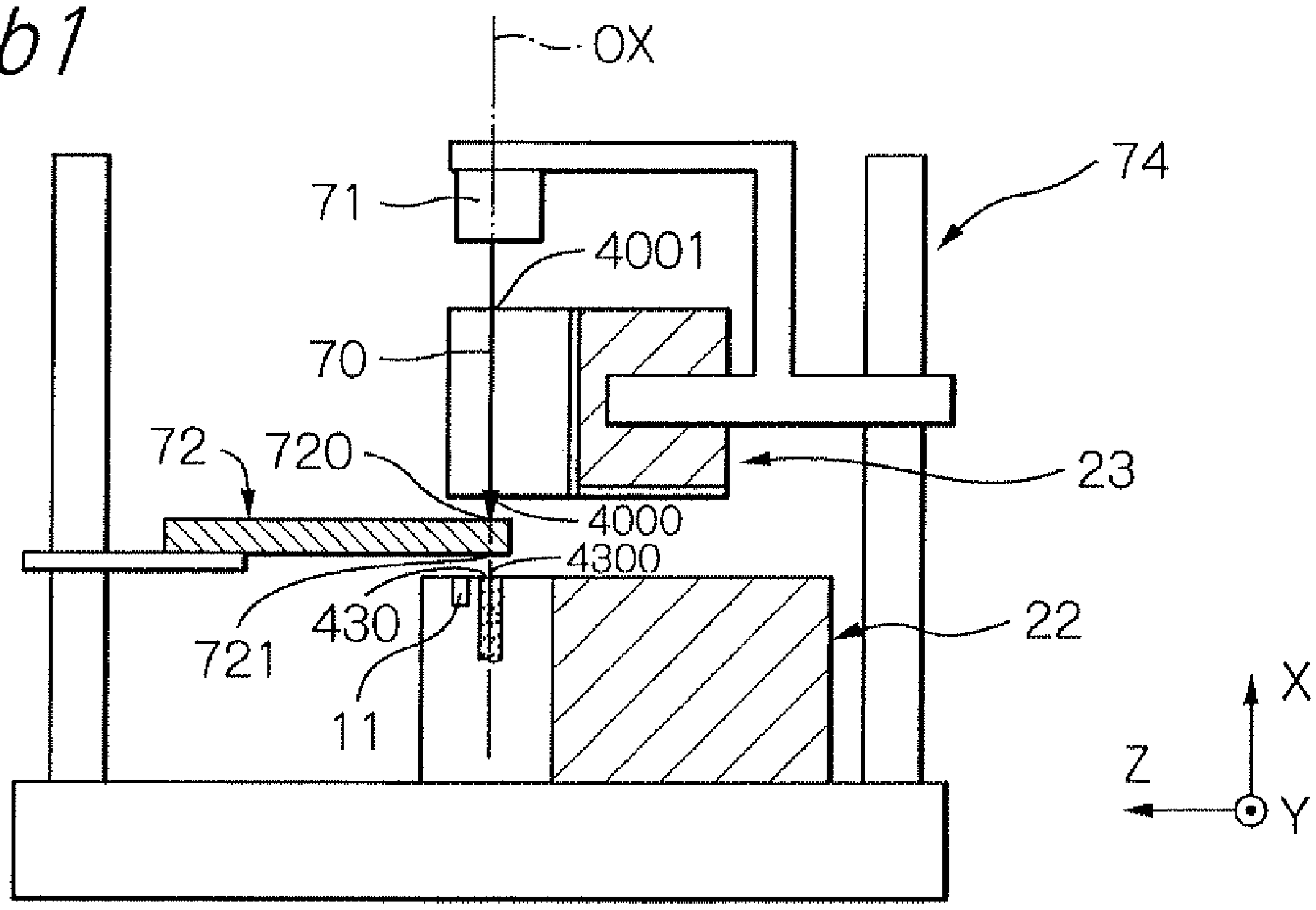

Fig. 6b2

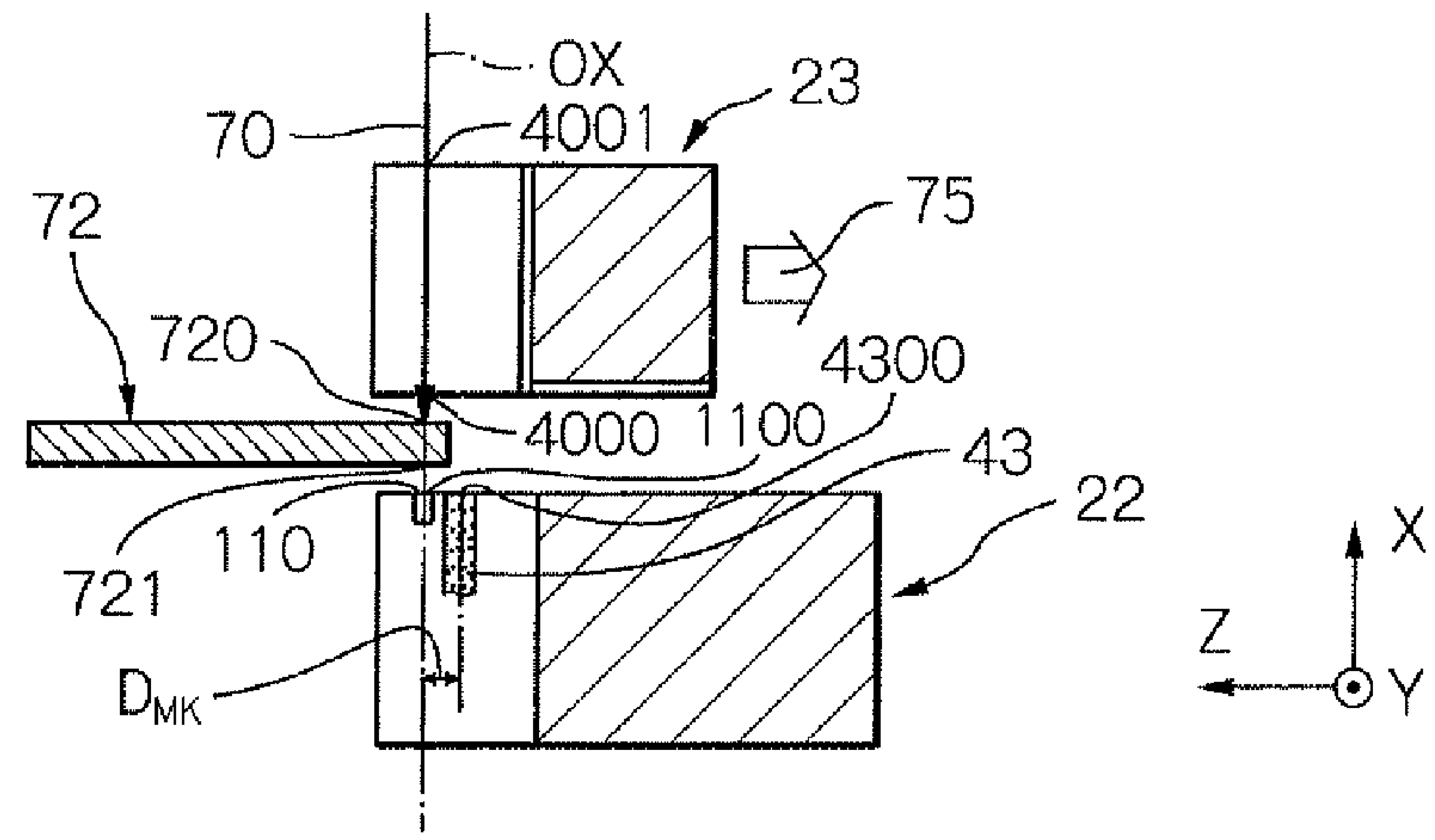

Fig. 6c

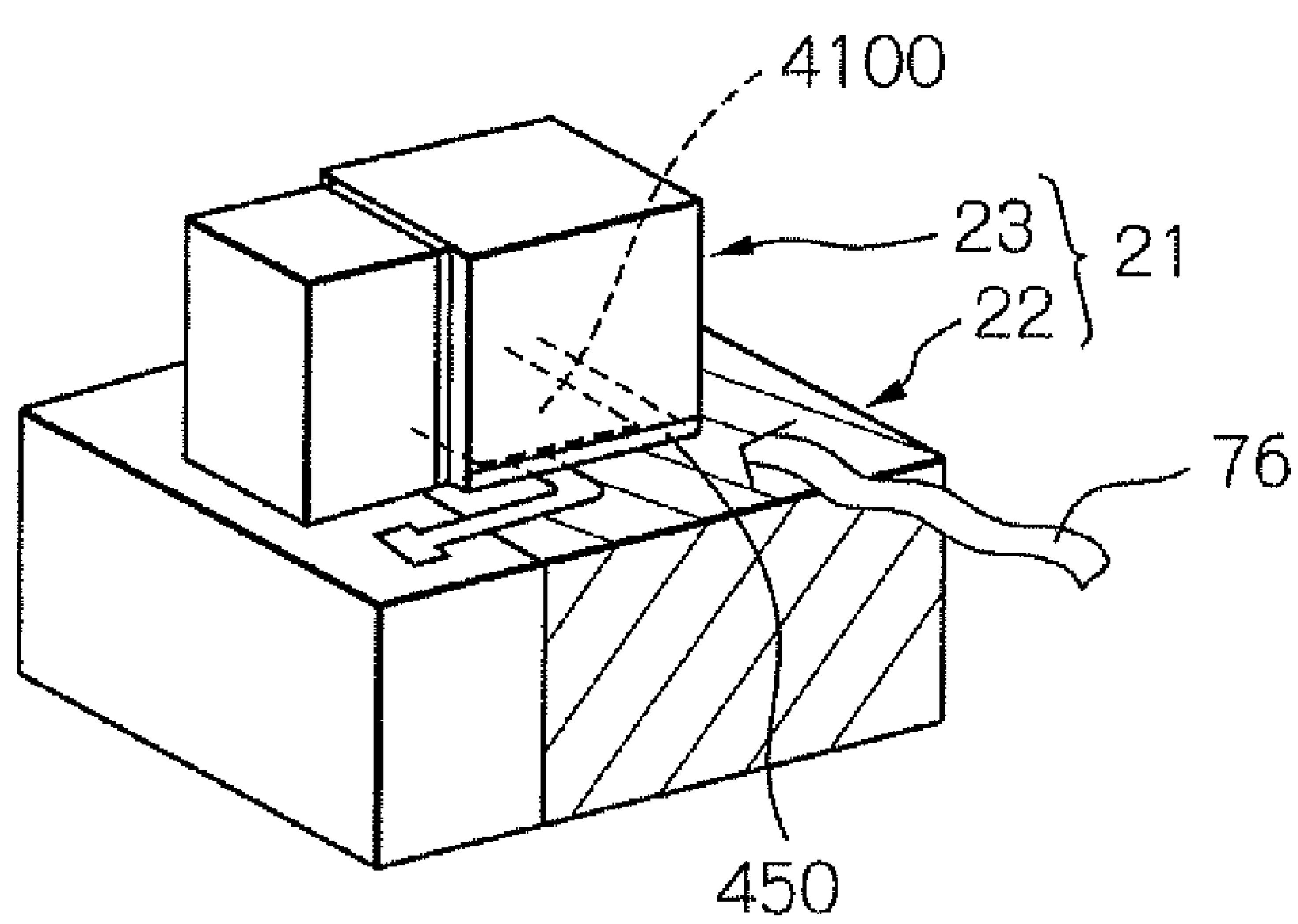

Fig. 7a

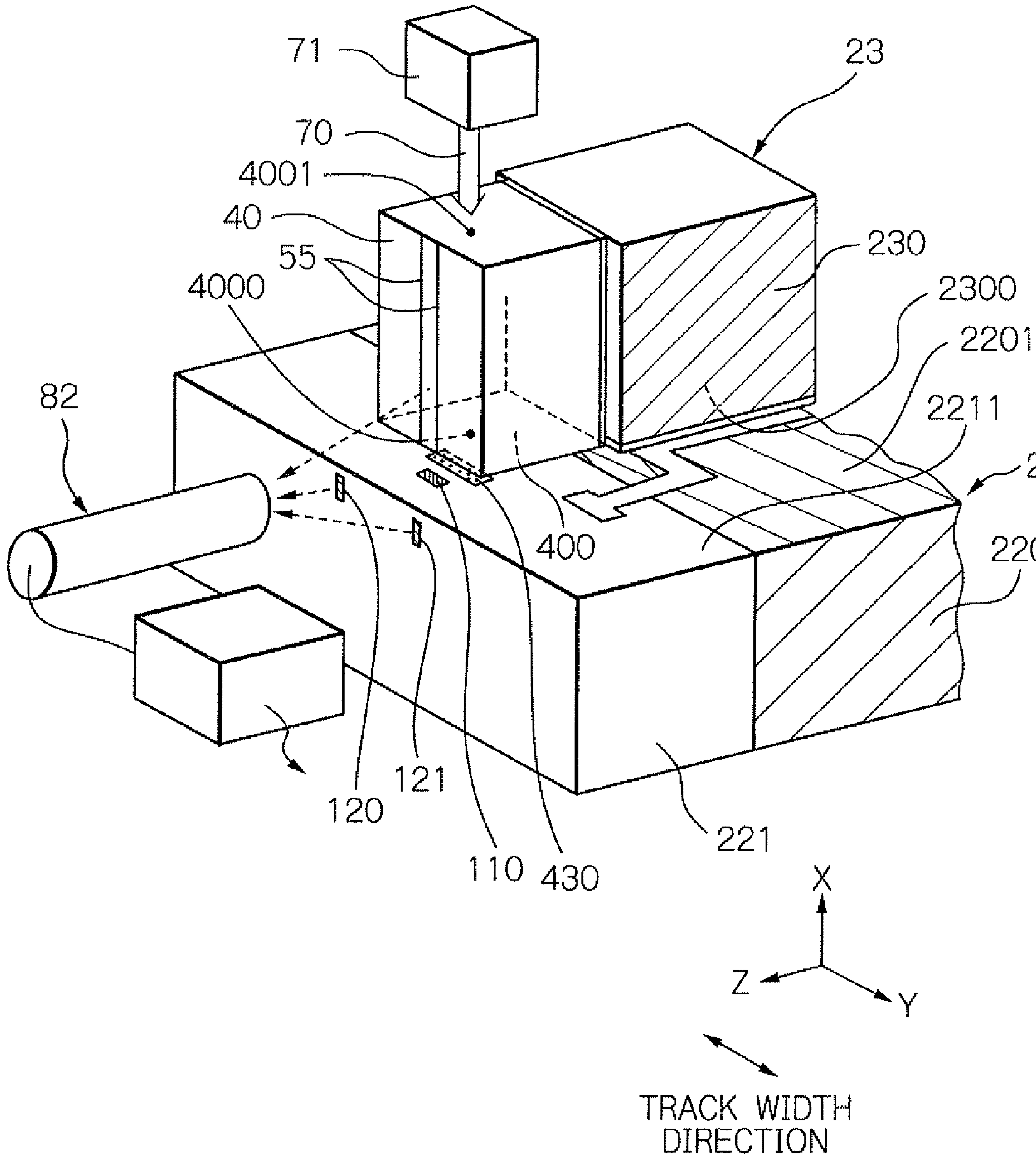
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Fig. 7b

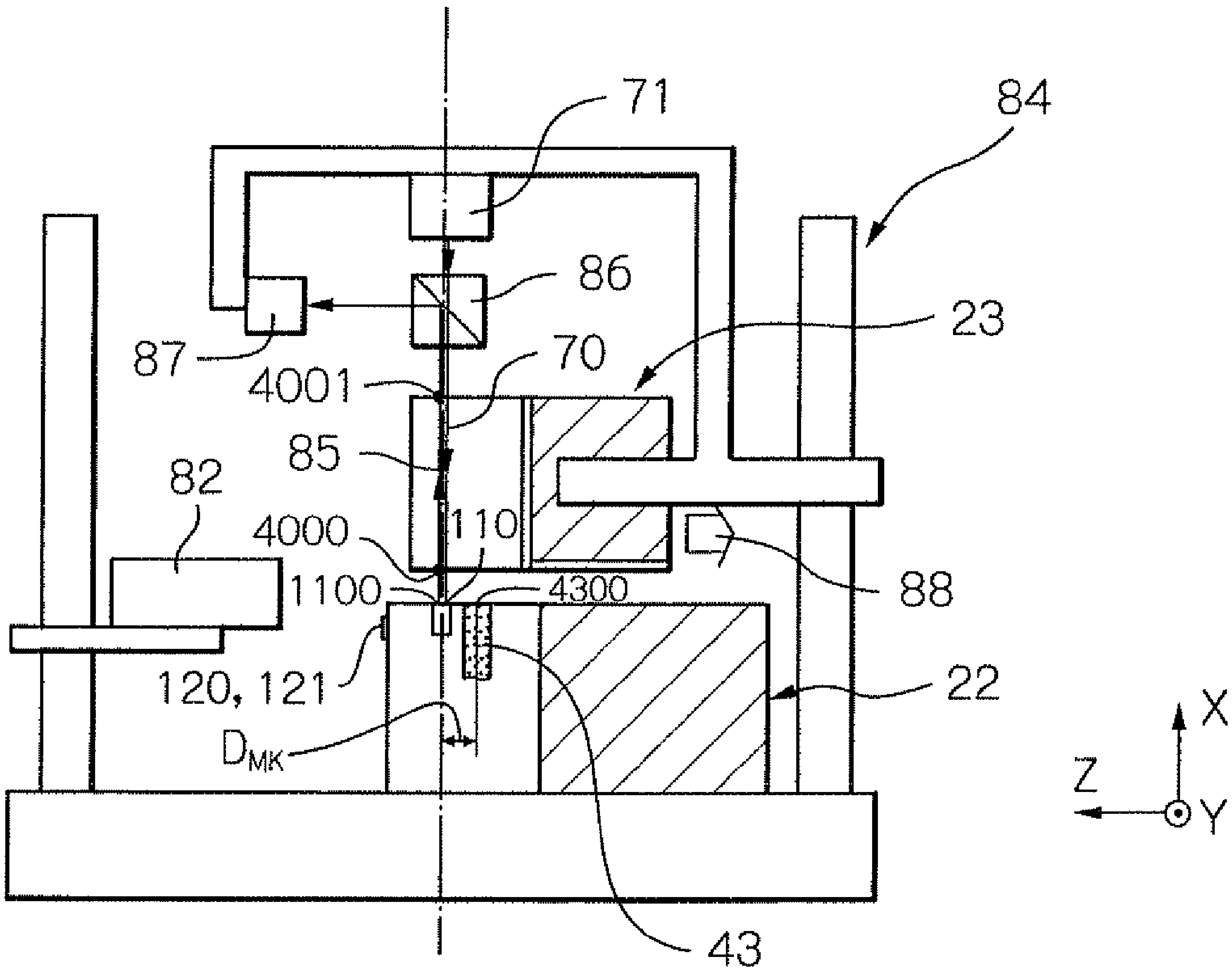

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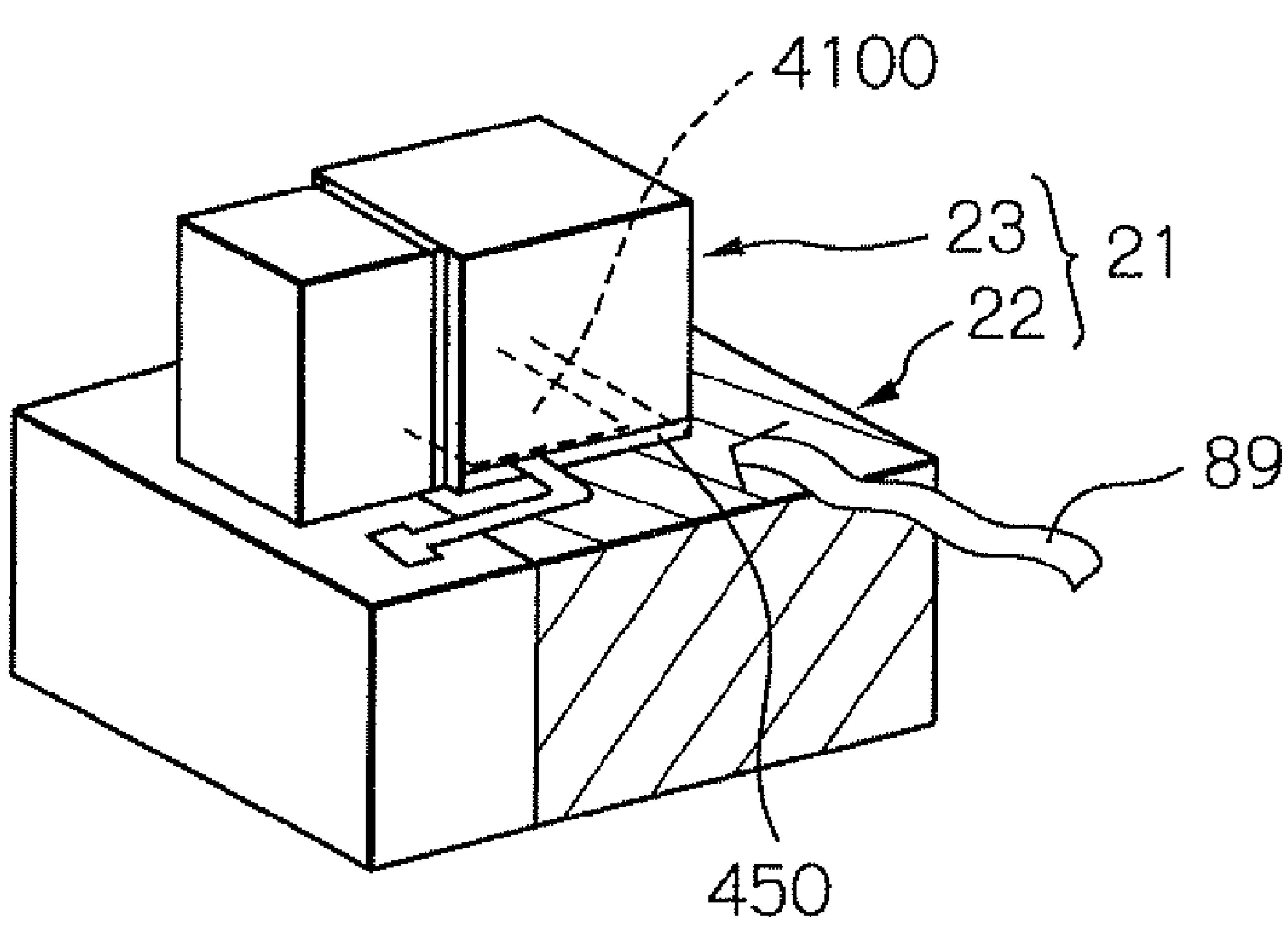
Fig. 7c



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METHOD FOR MANUFACTURING THERMALLY-ASSISTED MAGNETIC RECORDING HEAD BY SEMI-ACTIVE ALIGNMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a thermally-assisted magnetic recording head fabricated by joining a slider and a light source unit that includes a light source, and further relates to a method for manufacturing the thermally-assisted magnetic recording head.

2. Description of the Related Art

As the recording densities of magnetic recording apparatuses become higher, as represented by magnetic disk apparatuses, further improvement has been required in the performance of thin-film magnetic heads and magnetic recording media. As the thin-film magnetic heads, a composite-type thin-film magnetic head is widely used, which has a stacked structure of a magnetoresistive (MR) element for reading data and an electromagnetic transducer for writing data.

Whereas, the magnetic recording medium is generally a kind of discontinuous body of magnetic grains gathered together, and each of the magnetic grains has a single magnetic domain structure. Here, one record bit consists of a plurality of the magnetic grains. Therefore, in order to improve the recording density, it is necessary to decrease the size of the magnetic grains and reduce irregularity in the boundary of the record bit. However, the decrease in size of the magnetic grains raises a problem of degradation in thermal stability of the magnetization due to the decrease in volume.

As a measure against the thermal stability problem, it may be possible to increase the magnetic anisotropy energy K_U of the magnetic grains. However, the increase in energy K_U causes the increase in anisotropic magnetic field (coercive force) of the magnetic recording medium. Whereas, the intensity of write field generated from the thin-film magnetic head is limited almost by the amount of saturation magnetic flux density of the soft-magnetic material of which the magnetic core of the head is formed. As a result, the head cannot write data to the magnetic recording medium when the anisotropic magnetic field of the medium exceeds the write field limit.

Recently, as a method for solving the problem of thermal stability, so-called a thermally-assisted magnetic recording technique is proposed. In the technique, a magnetic recording medium formed of a magnetic material with a large energy K_U is used so as to stabilize the magnetization, then anisotropic magnetic field of a portion of the medium, where data is to be written, is reduced by heating the portion; just after that, writing is performed by applying write field to the heated portion.

In this thermally-assisted magnetic recording technique, there has been generally used a method in which a magnetic recording medium is irradiated and thus heated with a light such as near-field light. In this case, it is significantly important to stably supply a light with a sufficiently high intensity at a desired position on the magnetic recording medium. However, from the beginning, more significant problem to be solved exists in where and how a light source with a sufficiently high output of light should be disposed inside a head.

As for the setting of the light source, for example, U.S. Pat. No. 7,538,978 B2 discloses a configuration in which a laser unit including a laser diode is mounted on the back surface of a slider, and US Patent Publication No. 2008/0056073 A1 discloses a configuration in which a structure of a laser diode element with a monolithically integrated reflection mirror is mounted on the back surface of a slider. Further, US Patent Publication No. 2005/0213436 A1 discloses a structure of slider that is formed together with a semiconductor laser, and Robert E. Rottmayer et al. "Heat-Assisted Magnetic Recording" IEEE TRANSACTIONS ON MAGNETICS, Vol. 42, No. 10, p. 2417-2421 (2006) discloses a configuration in which a diffraction grating is irradiated with a light generated from a laser unit provided within a drive apparatus.

As described above, various types of the setting of the light source are suggested. However, the present inventors propose a thermally-assisted magnetic recording head with a "composite slider structure" which is constituted by joining a light source unit provided with a light source to the end surface (back surface) of a slider provided with a write head element, the end surface being opposite to the opposed-to-medium surface of the slider. The "composite slider structure" is disclosed in, for example, US Patent Publication No. 2008/043360 A1 and US Patent Publication No. 2009/052078 A1. The advantages of the thermally-assisted magnetic recording head with the "composite slider structure" are as follows:

a) The head has an affinity with the conventional manufacturing method of thin-film magnetic heads because the opposed-to-medium surface and the element-integration surface are perpendicular to each other in the slider.

b) The light source can avoid suffering mechanical shock directly during operation because the light source is provided far from the opposed-to-medium surface.

c) The light source such as a laser diode and the head elements can be evaluated independently of each other; thus the degradation of manufacturing yield for obtaining the whole head can be avoided; whereas, in the case that all the light source and head elements are provided within the slider, the manufacturing yield rate for obtaining the whole head is likely to decrease significantly due to the multiplication of the process yield for the light-source and the process yield for the head elements.

d) The head can be manufactured with reduced man-hour and at low cost, because of no need to provide the head with optical components such as a lens or prism which are required to have much high accuracy, or with optical elements having a special structure for connecting optical fibers or the like.

In fabrication of a thermally-assisted magnetic recording head having such a "composite slider structure", it is significantly important to accurately align the light source unit with the slider when joining them together.

In practice, the head need to be fabricated in such a way that light emitted from the light-emission center located in the light-emitting surface of the light source is reliably allowed to be incident exactly at the light-receiving end of an optical system such as a waveguide located on the back surface of the slider in order to provide a sufficiently high light use efficiency. To this end, the light-emission center and the light-receiving end are aligned with each other in the track width direction and in the direction perpendicular to the track width direction as accurately as possible. Typically, it is preferable that the accuracy of the alignment be within ±1 μm (micrometer) in actual manufacturing.

One approach to achieving such high alignment accuracy is active alignment. In the active alignment, a light source such as a laser diode is actually being activated while the light source and the optical system are moved relative to each other, light emitted from the light source and incident at the light-receiving end of the optical system is monitored on the light-emitting end side of the optical system in real time, and a monitoring position at which the highest light intensity is obtained is set as the desired relative position of the light source and the optical system. However, the active alignment is a method of merely locating a two-dimensional optimum position and has the drawback of requiring a considerably long time for alignment. In addition, power supply probes need to be applied to the electrodes of the light source in order to keep activating the light source during the alignment, which further increase the time required for the alignment. Furthermore, a head structure and probing facilities which are required for the probing increase the manufacturing load.

There is another approach called passive alignment. In the passive alignment, a light source and an optical system are physically coupled to each other or are moved through image recognition, thus to align them with each other using an existing groove, an existing projection, or a marker provided in the light source and/or the optical system as a mark for alignment. In general, the passive alignment takes a shorter time than the active alignment. However, the accuracy of the passive alignment tends to be low compared with the active alignment. In addition, it is considerably difficult to find or add a marker for the passive alignment on the light-source unit during fabrication of a head having the "composite slider structure".

In practice, in the "composite slider structure", the alignment target in the light source unit is the light-emission center located in the light-emitting surface of the light source. If the light source is an edge-emitting laser diode, an end of a ridge structure located at the light-emitting surface of the diode is as small as approximately $2\times2\ \mu m^2$, for example, and is difficult to observe. Furthermore, even if the end can be observed, it is extremely difficult to identify the light-emission center in the end of the ridge structure. It may be contemplated to provide a marker for passive alignment on the light-emitting surface. However, provision of a light source, such as a laser diode, to which a maker suitable for image recognition is given will significantly increase manufacturing cost.

Therefore, there is a need for a novel alignment method capable of aligning a light source unit and a slider with each other with a sufficiently high alignment accuracy in a short processing time in fabrication of a thermally-assisted magnetic recording head having a "composite slider structure".

SUMMARY OF THE INVENTION

Some terms used in the specification will be defined before explaining the present invention. In a layered structure or an element structure formed in the element-integration surface of a slider substrate or in the source-installation surface of a unit substrate of the magnetic recording head according to the present invention, when viewed from a standard layer or element, a substrate side is defined as "lower" side, and the opposite side as an "upper" side. Further, "X-, Y- and Z-axis directions" are indicated in some figures showing embodiments of the head according to the present invention as needed. Here, Z-axis direction indicates above-described "up-and-low" direction, and +Z side corresponds to a trailing side and −Z side to a leading side. And Y-axis direction indicates a track width direction, and X-axis direction indicates a height direction.

Further, a "side surface" of a waveguide provided within the magnetic recording head is defined as an end surface other than the end surfaces perpendicular to the direction in which light propagates within the waveguide (−X direction), out of all the end surfaces surrounding the waveguide. According to the definition, an "upper surface" and a "lower surface" are one of the "side surfaces". The "side surface" is a surface on which the propagating light can be totally reflected within the waveguide corresponding to a core.

According to the present invention, a method for manufacturing a thermally-assisted magnetic recording head in which a light source unit and a slider are joined to each other is provided. The light source unit includes a light source that is provided in a source-installation surface adjacent to a joining surface of a unit substrate and has a surface including a light-emission center on the joining surface side. The slider includes an optical system that is provided on an element-integration surface adjacent to an opposed-to-medium surface of a slider substrate and has a light-receiving end surface reaching a back surface opposite to the opposed-to-medium surface. The manufacturing method according to the present invention comprises the steps of:

causing a light to enter the light source from a surface opposite to the surface including the light-emission center of the light source while the joining surface of the light source unit is opposed to the back surface of the slider;

detecting the light that has passed through the light source and is emitted from the light-emission center to align the light-emission center of the light source unit with the light-receiving end surface of the slider; and

bonding the light source unit to the slider in such a way that the bonding surface and the back surface face to each other.

This manufacturing method according to the present invention utilizes an alignment method that uses a light for alignment that is entered into the light source from the opposite side to the light-emission center and is emitted from the light-emission center. This alignment method is hereinafter referred to as "semi-active alignment". The "semi-active alignment" can achieve the alignment of the light source unit and the slider with a sufficiently high alignment accuracy in a short processing time.

As one embodiment of the manufacturing method according to the present invention, it is preferable that a multi-field-of-view microscope is inserted between the joining surface of the light source unit and the back surface of the slider; and an alignment of the light-receiving end surface and the light-emission center is performed by using the multi-field-of-view microscope in such a way that the light-receiving end surface or a marker that is in a predetermined positional relation with the light-receiving end surface is captured by a different field of view from a field of view that captures a light emitted from the light-emission center. Here, a dual-field-of-view microscope is preferably used as the multi-field-of-view microscope, which comprises two objective lenses in respective upper and lower surfaces of the microscope, optical axes of the two objective lenses being in a predetermined positional relation with each other.

As another embodiment of the manufacturing method according to the present invention, it is preferable that the light source unit and the slider are moved relative to each other from reference positions by a predetermined amount to align the light source unit and the slider with each other, the reference positions being positions in which the light-emission center and the light-receiving end surface are located when a light emitted from the light-emission center, reflected by a marker, reentering the light source, and then passing through the light source, is emitted from the surface opposite to the surface including the light-emission center, the marker being provided on the back surface of the slider and being in a predetermined positional relation with the light-receiving end surface. Further, in this embodiment, it is more preferable that the alignment of the light source unit and the slider is performed using reference positions in which the light-emission center and the light-receiving end surface are located when an intensity of the light that reenters the light source and is emitted from the surface opposite to the surface including the light-emission center becomes maximum.

In the above-described another embodiment, it is also preferable that a marker layer made of a material that reflects the light is formed at a position above the element-integration surface of the slider substrate and apart from the optical system with a predetermined distance in a direction perpendicular to the element-integration surface, and an end surface of the marker layer is used as the marker, the end surface reaching the back surface. The distance can be controlled with an ultrahigh accuracy achieved by thin-film formation technology. Further, in the another embodiment, it is also preferable that an alignment in a track width direction of the light source and the light-receiving end surface is performed by using an additional marker that is provided in the element-integration surface of the slider substrate and is in a predetermined positional relation with the light-receiving end surface in the track width direction. Furthermore, it is preferable that a distance between the surface including the light-emission center of the light source and the back surface is set to be 2 μm (micrometers) or more and to be 20 μm or less when aligning the light-emission center of the light source unit and the light-receiving end surface of the slider with each other.

According to the present invention, a slider is further provided, which is to be joined to a light source unit by the above-described manufacturing method to form a thermally-assisted magnetic recording head, the light source unit including a light source that is provided in a source-installation surface adjacent to a joining surface of a unit substrate and has a surface including a light-emission center on the joining surface side. The slider comprises:

a slider substrate including an opposed-to-medium surface;

a write head element provided in an element-integration surface adjacent to the opposed-to-medium surface of the slider substrate, for writing data on a magnetic recording medium;

an optical system provided in the element-integration surface of the slider substrate and having a light-receiving end surface reaching to a back surface of the slider, for propagating a light for thermal assist to the opposed-to-medium surface side; and

a marker provided on the back surface of the slider and being in a predetermined positional relation with the light-receiving end surface.

In this slider according to the present invention, it is preferable that a marker layer made of a material that reflects a light for alignment is provided at a position above the element-integration surface of the slider substrate and apart from the optical system with a predetermined distance in a direction perpendicular to the element-integration surface, and the marker is an end surface of the marker layer, the end surface reaching the back surface of the slider. Further, it is also preferable that an additional marker that is in a predetermined positional relation with the light-receiving end surface in the track width direction is provided in the element-integration surface of the slider substrate.

According to the present invention, a thermally-assisted magnetic recording head is furthermore provided, which comprises: a light source unit comprising a light source provided in a source-installation surface adjacent to a joining surface of a unit substrate; and a slider as claimed in claim **9** that is joined with the light source unit, a surface that includes the light-emission center of the light source being positioned on the joining surface side.

Further objects and advantages of the present invention will be apparent from the following description of preferred embodiments of the invention as illustrated in the accompanying figures. In each figure, the same element as an element shown in other figure is indicated by the same reference numeral. Further, the ratio of dimensions within an element and between elements becomes arbitrary for viewability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view and a cross-sectional view schematically illustrating an embodiment in which a thermally-assisted magnetic recording head according to the present invention is attached on a flexure of a head gimbal assembly (HGA);

FIG. **2** shows a perspective view illustrating one embodiment of the thermally-assisted magnetic recording head according to the present invention;

FIG. **3** shows a perspective view illustrating the structure of the laser diode and the state of joining the laser diode to the unit substrate;

FIG. **4** shows a cross-sectional view taken by plane A in FIG. **3**, schematically illustrating the configuration of the head element and its vicinity in the thermally-assisted magnetic recording head;

FIG. **5** shows a perspective view schematically illustrating the configuration of the waveguide, the surface plasmon generator and the main magnetic pole;

FIGS. **6***a* to **6***c* show schematic views illustrating one embodiment of a method for manufacturing the thermally-assisted magnetic recording head using the semi-active alignment according to the present invention; and

FIGS. **7***a* to **7***c* show schematic views illustrating another embodiment of a method for manufacturing the thermally-assisted magnetic recording head using the semi-active alignment according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a perspective view and a cross-sectional view schematically illustrating an embodiment in which a thermally-assisted magnetic recording head **21** according to the present invention is attached on a flexure **201** of a head gimbal assembly (HGA). In the perspective view, the side of the head **21** opposed to the surface of the magnetic disk is turned downward.

As shown in FIG. **1**, the thermally-assisted magnetic recording head **21** is constituted by joining a light source unit **23** including a laser diode **40** as a light source to a slider **22**. The slider **22** includes a slider substrate **220** and a head element part **221** provided on the element-integration surface of the slider substrate **220**. The head element part **221** includes: an optical system **31** for guiding laser light generated from the laser diode **40** toward the opposed-to-medium surface side and for generating a light (near-field light) for thermal assist; and a head element **32** for writing and reading data. Further, a flexure **201** has an aperture **2010**; the light source unit **23** protrudes from the aperture **2010** on the side opposite to the slider **22** in relation to the flexure **201**.

Further, the slider **22** includes a pair of terminal electrodes **370** and a pair of terminal electrodes **371**, which are provided for the head element **32**, and two terminal electrodes **410** and **411** for the laser diode **40**. These terminal electrodes **370**, **371**, **410** and **411** are electrically connected to the connection pads **2031** of a wiring member **203** provided on the flexure **201**. The terminal electrode **410** is electrically connected to a back surface electrode **4100** that is provided on the end surface (back surface) **2201** of the slider substrate **220** and is formed of a conductive material such as gold (Au) or Au alloy, the back surface **2201** being opposite to the opposed-to-medium surface (air bearing surface: ABS) **2200** of the slider substrate **220**. Further, the terminal electrode **410** is electrically connected to n-electrode layer **40***a* of the laser diode **40** through the back surface electrode **4100**. The terminal electrode **411** is electrically connected to p-electrode layer **40***i* of the laser diode **40**. This connection between the terminal electrodes **411** and the p-electrode layer **40***i* can be achieved by wire bonding, or by solder ball bonding (SBB) with use of a solder.

Fixing of the head **21** onto the flexure **201** and electrical connection of terminal electrodes **370**, **371**, **410** and **411** to connection pads **2031** of the wiring member **203** can be performed at a time by using an anisotropic conductive resin **56** as illustrated in the cross-sectional view shown in FIG. **1**. The anisotropic conductive resin **56** includes: an adhesive portion **560** made of an ultraviolet (UV) curable resin such as UV curable epoxy resin or UV curable acrylic resin, which hardens on exposure to ultraviolet light, or a thermosetting resin, which hardens when heated; and a conductive filler **561** dispersed in the adhesive portion **560**, made of metal particles such as silver (Ag) particles or plastic particles coated with a metal. The anisotropic conductive resin **56** is provided between the flexure **201** and the back surface **2201** of the slider substrate **220** as well as the end surface **2211** of the head element part **221**, and bonds them together. The anisotropic conductive resin **56** is also provided between each of the terminal electrodes **370**, **371**, **410** and **411** and the connection pad **2031**. The anisotropic conductive resin is described in Japanese Patent Publication No. 11-185232, for example. Alternatively, each of the terminal electrodes **370**, **371**, **410** and **411** can be electrically connected to its corresponding connection pad **2031** by using other means, for example wire bonding, instead of the anisotropic conductive resin **56**.

In the mode in which the thermally-assisted magnetic recording head **21** is mounted on the flexure **201** as described above, stable fixation and proper electrical connection can be achieved even though the light source unit **23** is protruded from the slider **22**. In particular, since the terminal electrodes **370**, **371**, **410** and **411** of the head **21** are concentrated on the end surface **2211**, the wiring member **203**, which is electrically connected to these terminal electrodes, needs to be provided only on one of the surfaces of the flexure **201** (that is on the slider side). The arrangement of the wiring member **203** further ensures the electrical connection to the terminal electrodes of the head **21** and also facilitates the fabrication of the head gimbal assembly (HGA), contributing to increase of the production yields.

FIG. **2** shows a perspective view illustrating one embodiment of the thermally-assisted magnetic recording head **21** according to the present invention.

As shown in FIG. **2**, a thermally-assisted magnetic recording head **21** is constituted of a slider **22** and a light source unit **23** as described above. The slider **22** includes: a slider substrate **220** having an air bearing surface (ABS) **2200** processed so as to provide an appropriate flying height, and formed of, for example, AlTiC (Al_2O_3—TiC); and a head element part **221** formed on an element-integration surface **2202** that is perpendicular to and adjacent to the ABS **2200**. While, the light source unit **23** includes: a unit substrate **230** having an joining surface **2300**, and formed of, for example, AlTiC (Al_2O_3—TiC); and a laser diode **40** as a light source provided on a source-installation surface **2302** that is perpendicular to and adjacent to the joining surface **2300**. The slider **22** and the light source unit **23** are bonded to each other in such a way that the back surface **2201** of the slider substrate **220** and the joining surface **2300** of the unit substrate **230** are opposed to each other.

In the slider **22**, the head element part **221** formed on the element-integration surface **2202** of the slider substrate **220** includes: a head element **32** constituted of a magnetoresistive (MR) element **33** for reading data from a magnetic disk and an electromagnetic transducer **34** for writing data to the magnetic disk; a spot-size converter **43** that receives a laser light emitted from the laser diode **40**, changes (reduces) the spot size of the laser light, then guides the laser light into the waveguide **35**; a waveguide **35** that guides the laser light with changed spot size to the head end surface **2210** or its vicinity; a surface plasmon generator **36** that generates near-field light for thermal assist; and an overcoat layer **38** formed on the element-integration surface **2202** so as to cover the head element **32**, the spot-size converter **43**, the waveguide **35** and the surface plasmon generator **36**. Here, the spot-size converter **43**, the waveguide **35** and the surface plasmon generator **36** constitute the optical system **31** for generating near-field light in the head **21**.

One ends of the MR element **33**, the electromagnetic transducer **34** and the surface plasmon generator **36** reach the head end surface **2210** as an opposed-to-medium surface. Here, the head end surface **2210** and the ABS **2200** constitute the whole opposed-to-medium surface of the thermally-assisted magnetic recording head **21**. During actual write and read operations, the thermally-assisted magnetic recording head **21** aerodynamically flies above the surface of the rotating magnetic disk with a predetermined flying height. Thus, the ends of the MR element **33** and electromagnetic transducer **34** face the surface of the magnetic record layer of the magnetic disk **10** with a appropriate magnetic spacing. Then, MR element **33** reads data by sensing signal magnetic field from the magnetic record layer, and the electromagnetic transducer **34** writes data by applying signal magnetic field to the magnetic record layer. When writing data, laser light, which is generated from the laser diode **40** of the light source unit **23** and propagates through the spot-size converter **43** and the waveguide **35**, is changed into near-field light in the surface plasmon generator **36**. Then, a portion to be written of the magnetic recording layer is irradiated and thus heated with the near-field light. As a result, the anisotropic magnetic field (coercive force) of the portion is decreased to a value that enables writing; thus the thermally-assisted magnetic recording can be achieved.

Referring also to FIG. **2**, the spot-size converter **43** is an optical element which receives, at its light-receiving end surface **430** having a width W_{SC} in the track width direction (the Y-axis direction), laser light emitted from the laser diode **40**, converts the laser light to laser light with a smaller spot diameter with a low loss while maintaining a single mode, and then guides the converted laser light to a light-receiving end surface **352** of the waveguide **35**. The spot-size converter **43** in the present embodiment includes a lower propagation layer **431** and an upper propagation layer **432**. The lower propagation layer **431** has a width in the track width direction (the Y-axis direction) that gradually decreases from the width W_{SC} along the traveling direction (−X direction) of laser light incident through the light-receiving end surface **430**. The upper propagation layer **432** is stacked on the lower propagation layer **431** and has a width in the track width direction (Y-axis direction) that more steeply decreases from the width W_{SC} along the traveling direction (−X direction) of laser light than the lower propagation layer **431**. Laser light incident through the light-receiving end surface **430** is converted to laser light with a smaller spot size as the laser light propagates through the layered structure, and reaches the light-receiving end surface **352** of the waveguide **35**.

The width W_{SC} of the spot-size converter **43** at the light-receiving end surface **430** may be in the range of approximately 1 to 10 μm (micrometers), for example. The thickness T_{SC} (in Z-axis direction) at the light-receiving end surface **430** may be in the range of approximately 1 to 10 μm, for example. The light-receiving end surface **430** is preferably inclined at a predetermined acute angle, for example at an angle of approximately 4 degrees with respect to the end surface **400** including the light-emission center **4000** of the laser diode **40**. Such angle prevents laser light reflected by the light-receiving end surface **430** from returning to the light-emission center **4000**. The spot-size converter **43** is made of a material with a refractive index higher than the refractive index n_{OC} of the constituent material of the surrounding overcoat layer **38**. The spot-size converter **43** can be formed from the same dielectric material as the waveguide **35**, which will be described below. In the case, the spot-size converter **43** and the waveguide **35** may be formed integrally.

The waveguide **35** in the present embodiment extends in parallel with the element-integration surface **2202** from the light-receiving end surface **352** that receives laser light emitted from the spot-size converter **43** to the end surface **350** on the head end surface **2210** side. One side surface of the waveguide **35** near the end surface **350** faces a surface plasmon generator **36**. This allows laser light (waveguide light) incident through the light-receiving end surface **352** and traveling through the waveguide **35** to reach the portion facing the surface plasmon generator **36**.

The head element part **221** further includes a marker **110** on the end surface **2211** that is a portion of the back surface of the slider **22**. The marker **110** is made of a material such as a metal that reflects alignment light used in "semi-active alignment" according to the present invention, which will be described later in detail. The marker **110** is in a predetermined positional relation with the light-receiving end surface **430** of the spot-size converter **43**. For example, the marker **110** is provided on the trailing side (+Z side) at a distance D_{MK} (from the light-receiving end surface **430**. The distance D_{MK} (is the distance between the center **4300** of the light-receiving end surface **430** and the center **1100** of the marker **110** in Z-axis direction and can be set to a value in the range of 1 to 5 μm, for example. Preferably, the center line that passes through the center **4300** of the light-receiving end surface **430** along Z-axis direction coincides with the center line that passes through the center **1100** of the marker **110** along Z-axis direction. The "semi-active alignment" according to the present invention can be accomplished by using the marker **110**, as will be detailed later. The marker **110** may alternatively be provided on the back surface **2201** of the slider substrate **220**.

The head element part **221** further includes additional markers **120** and **121** on its upper surface **2212** (which is the upper surface of an overcoat layer **38**). The additional markers **120** and **121** are made of a metal such as Au (gold) and are large enough in area to be observable under a microscope during alignment. The additional markers **120** and **121** are in predetermined positional relations with the light-receiving end surface **430** of the spot-size converter **43** in the track width direction (Y-axis direction) and are provided at distances $-D_u$ and D_{MK2}, respectively, in the track width direction from the center line that passes through the center **4300** of the light-receiving end surface **430** along Z-axis direction. The distance D_{MK2} can be set to a value in the range of 1 to 5 μm, for example. The additional markers **120** and **121** enable reliable alignment between the slider **22** and the light source unit **23** in Y-axis direction during fabrication of the head, as will be described later in detail. The number of additional markers is not limited to two; a single marker or more than two markers may be provided in (a) predetermined positional relation(s) with the light-receiving end surface **430** in the track width direction.

Referring again to FIG. **2**, the light source unit **23** includes: a unit substrate **230** having a joining surface **2300**; and a laser diode **40** provided on the source-installation surface **2302** which is perpendicular to and adjacent to the joining surface **2300** of the unit substrate **230**. A first unit electrode **450** is provided on the joining surface **2300** of the unit substrate **230**, and a second unit electrode **451** is provided on the source-installation surface **2302** of the unit substrate **230**. The first unit electrode **450** and the second unit electrode **451** cover the two respective adjacent end surfaces of the unit substrate **230** so that the first and second unit electrodes **450** and **451** are electrically interconnected and form an integral electrode. The first and second unit electrodes **450** and **451** may be formed by a foundation layer of a material such as Ta or Ti with a thickness of approximately 10 nm (nanometers), for example, and a conducting layer stacked on the foundation layer and formed of a conductive material such as gold (Au), copper (Cu) or an alloy of Au with a thickness in the range of approximately 1 to 5 μm, for example.

The laser diode **40** is provided on the source-installation surface **2302** in such a manner that an n-electrode layer **40***a* and the second unit electrode **451** are bonded together and electrically interconnected. The light source unit **23** on which the laser diode **40** is mounted is mounted on the slider **22** in such a manner that the first unit electrode **450** and the back surface electrode **4100** provided on the back surface **2201** of the slider substrate **220** are bonded together and electrically interconnected. Accordingly, the terminal electrode **410** provided on the head end surface **2211** of the slider **22** is electrically connected to the n-electrode layer **40***a* of the laser diode **40** through the back surface electrode **4100** and the first and second unit electrodes **450** and **451**. The back surface electrode **4100** bonded with the first unit electrode **450** functions as an electrode for supplying power to the light source provided on the slider **22**. When a predetermined voltage is applied between the n-electrode layer **40***a* and a p-electrode layer **40***i* of the laser diode **40** through the terminal electrodes **410** and **411** in the thermally-assisted magnetic recording head **21** completed by joining the light source unit **23** to the slider **22**, the laser diode **40** oscillates and laser light is emitted from the light-emission center **4000**.

As also shown in FIG. **2**, the slider substrate **220** is, for example, a so-called Femto slider having a thickness (in X-axis direction) T_{SL} of 230 μm, a width W_{SL} of 700 μm in the track width direction (Y-axis direction), and a length L_{SL} (in Z-axis direction) of 850 μm. The Femto slider is commonly used as the substrate of a thin-film magnetic head capable of achieving a high recording density and is the smallest in standardized size among the currently used sliders. The back surface **2201** of the slider substrate **210** in this case has an area of 850 μm (L_{SL})×700 μm (W_{SL}). The area contains the region in which the back-surface electrode **4100** is to be formed and the light source unit **23** is to be mounted and the region to be bonded to the flexure **201** (FIG. **1**).

On the other hand, the unit substrate **230** is somewhat smaller than the slider substrate **220**. In particular, the width W of the unit substrate **230** in the track width direction (Y-axis direction) is preferably smaller than the width W_{SL} of the slider substrate **220**, greater than or equal to the width W_{LA}, of the laser diode **40** in the track width direction (Y-axis direction), and less than or equal to 1.5 times the width W. The unit substrate **230** may have a thickness T_{UN} (in X-axis direction) of 320 μm, a width W_{UN} in the track width direction (in Y-axis direction) of 300 μm, and a length L_{UN} (in Z-axis direction) of 250 μm, for example, if the laser diode **40** to be used has a length L_{LA} of 300 μm and a width W_{LA} of 200 μm, for example. The height T_{LA} of the laser diode **40** is in the range of, for example, 60 to 200 μm. As seen from the above, the light source unit **23** according to the present invention can be adequately reduced in size to reduce the weight. The reduction of the weight maintains and enhances the flying performance and impact resistance of the head **21** in operation which has the light source unit **23** mounted on the slider **22** and is attached to the flexure **203** (FIG. **1**).

Referring again to FIG. **2**, the thermally-assisted magnetic recording head **21** has the structure in which the slider **22** and the light source unit **23** are interconnected as described above. Thus, the slider **22** and the light source unit **23** can be separately fabricated and then combined together to fabricate the head **21**. Consequently, the production yield of the entire heads is about the same as the production yield of the sliders **22** if performance evaluation of the light source units **23** is performed prior to the fabrication of the heads and only good light source units **23** are used for the fabrication of the heads. Thus, the reduction of production yield of the entire heads due to the rejection rate of the laser diodes **40** can be avoided.

FIG. **3** shows a perspective view illustrating the structure of the laser diode **40** and the state of joining the laser diode **40** to the unit substrate **230**.

According to FIG. **3**, the laser diode **40** is, in the present embodiment, of edge-emitting type. As the laser diode **40**, InP base, GaAs base or GaN base diodes can be utilized, which are usually used for communication, optical disk storage, or material analysis. The wavelength λ_L of the emitted laser light may be, for example, in the range of approximately 375 nm to 1.7 μm. Here, the laser diode **40** shown in FIG. **3** has a multilayered structure in which sequentially stacked from the unit substrate **230** side is: an n-electrode layer **40***a* having a surface contact and bonded with the second unit electrode **451**; an n-GaAs substrate **40***b*; an n-InGaAlP clad layer **40***c*; the first InGaAlP guide layer **40***d*; an active layer **40***e* formed of multiquantum well (InGaP/InGaAlP) or the like; the second InGaAlP guide layer **40***f*; an p-InGaAlP clad layer **40***g*; a p-electrode base layer **40***h*; and a p-electrode layer **40***i*. The upper surface of the p-electrode layer **40***i*, which is equivalent to the upper surface of the laser diode **40**, has grooves **55** extending in X-axis direction and corresponding to the ridge structure of laser diode. The ridge structure is formed of concavity and convexity that exist on the p-electrode layer side and ranges over the clad layer, and is provided for confining the laser light and concentrating it on the light-emission center. Here, the n-electrode layer **40***a* and the p-electrode layer **40***i* may be formed of, for example, gold (Au) or Au alloy with thickness of approximately 5 μm.

As described above, the laser diode **40** has a structure in which a multilayer including an active layer **40***e* is sandwiched between the n-electrode layer **40***a* and the p-electrode layer **40***i*. Here, the n-electrode layer **40***a* is located on the side opposite to the ridge structure and the active layer **40***e* is located closer to the p-electrode layer **40***i* than the n-electrode layer **40***a*. Accordingly, the light-emission center **4000** is located farther from the joining surface **2300** of the unit substrate **230** in Z-axis direction when the n-electrode layer **40***a* is bonded onto the unit substrate **230** as described above than when the p-electrode layer **40***i* is bonded onto the unit substrate **230**. Consequently, alignment of the laser diode **40** with the unit substrate **230** can be performed by means of a positioning jig having a flat surface when the laser diode **40** is bonded onto the unit substrate **230**. Specifically, the position of the laser diode **40** relative to the unit substrate **230** can be determined by butting a portion of the light-emitting surface **400** of the laser diode **40** on the unit substrate **230** side that does not include the light-emission center **4000** and at least a portion of the surface of the first unit electrode **450** against the flat surface of the positioning jig. In doing so, at least the light-emission center **4000** is prevented from suffering mechanical stress.

When the n-electrode layer **40***a* is bonded to the unit substrate **230**, the ridge structure including the grooves **55** lies in the upper surface of the laser diode **40** as described above. Therefore, in the head manufacturing, the ridge structure (grooves **55**) can be used as a mark that is to be aligned with the additional markers **120** and **121** when alignment of the slider **22** and light source unit **23** in Y-axis direction is performed with use of the additional markers **120** and **121**.

On the front and rear cleaved surfaces of the multilayered structure of the laser diode **40**, respectively formed are reflective layers **510** and **511** for exciting the oscillation by total reflection. The outer surface of the reflective layer **510** on the joining surface **2300** side is a light-emission surface **400**. Further, in the reflective layer **510**, there is an opening **5100** in the position of the active layer **40***e* including the light-emission center **4000**. Furthermore, in the reflective layer **511**, and there is an opening **5110** in the position of the active layer **40***e* including the rear light-emission center **4001**. The positions of the openings **5100** and **5110** are set in such a way that an alignment light **70** that enters the laser diode **40** from the opening **5110** is emitted from the opening **5100**.

Referring again to FIG. **3**, the n-electrode layer **40***a* of the laser diode **40** and the second unit electrode **451** of the unit substrate **230** can be bonded to each other by soldering using one of lead-free solders such as Au—Sn alloy 52, for example. Alternatively, they can be bonded together by using a conductive adhesive resin. Here, preferably the laser diode **40** is bonded onto the unit substrate **230** in such a way that the distance D_{REC} between the light-emitting surface **400** of the laser diode **40** and the surface **4500** of the first unit electrode **450** provided on the joining surface **2300** in the direction perpendicular to the surface **4500** (X-axis direction) is 0 or more, and 5 μm or less.

FIG. **4** shows a cross-sectional view taken by plane A in FIG. **3**, schematically illustrating the configuration of the head element **32** and its vicinity in the thermally-assisted magnetic recording head **21**.

As shown in FIG. **4**, the MR element **33** is formed on a base layer **380** that is formed of an insulating material such as Al_2O_3 (alumina), SiO_2 and stacked on the element-integration surface **2102**. The MR element **33** includes: an MR multilayer **332**; and a lower shield layer **330** and an upper shield layer **334** which sandwich the MR multilayer **332** and an insulating layer **381** therebetween. The MR multilayer **332** is a magneto-sensitive part for detecting signal magnetic field by utilizing MR effect. The MR multilayer **332** may be, for example: a current-in-plane giant magnetoresistive (CIP-GMR) multilayer that utilizes CIP-GMR effect; a current-perpendicular-to-plane giant magnetoresistive (CPP-CMR) multilayer that utilizes CPP-GMR effect; or a tunnel magnetoresistive (TMR) multilayer that utilizes TMR effect. In the case that the MR multilayer **332** is a CPP-GMR multilayer or a TMR multilayer, the upper and lower shield layers **334** and **330** act as not only magnetic shields but also electrodes.

Referring also to FIG. **4**, the electromagnetic transducer **34** is designed for perpendicular magnetic recording, and includes an upper yoke layer **340**, a main magnetic pole **3400**, a write coil layer **343**, a coil-insulating layer **344**, a lower yoke layer **345**, and a lower shield **3450**.

The upper yoke layer **340** is formed so as to cover the coil-insulating layer **344**, and the main magnetic pole **3400** is formed on an insulating layer **385** made of an insulating material such as Al_2O_3 (alumina). These upper yoke layer **340** and main magnetic pole **3400** are magnetically connected with each other, and acts as a magnetic path for converging and guiding magnetic flux toward the magnetic recording layer (perpendicular magnetization layer) of the magnetic disk, the magnetic flux being excited by write current flowing through the write coil layer **343**. The main magnetic pole **3400** includes: a first main pole portion **3400*a*** reaching the head end surface **2210** and having a small width W_P (FIG. **5**) in the track width direction; and a second main pole portion **3400*b*** located on the first main pole portion **3400*a*** and at the rear (+X side) of the portion **3400*a***. The first main pole portion **3400*a*** has an end surface **3400*e*** (FIG. **5**) with a shape of, for example, a rectangle, a square or a trapezoid on the head end surface **2210**. Here, the above-described width W_P, is the length of an edge in the track width direction (Y-axis direction) of the end surface **3400*e***, and defines the width of write field distribution in the track width direction (Y-axis direction). The width W_P can be set to be, for example, 0.05 to 0.5 μm. The main magnetic pole **3400** is preferably formed of a soft-magnetic material with a saturation magnetic flux density higher than that of the upper yoke layer **340**, which is, for example, an iron alloy containing Fe as a main component, such as FeNi, FeCo, FeCoNi, FeN or FeZrN. The thickness of the first main pole portion **3400*a*** is, for example, in the range of approximately 0.1 to 0.8 μm.

The write coil layer **343** is formed on an insulating layer **385** made of an insulating material such as Al_2O_3 (alumina), in such a way as to pass through in one turn at least between the lower yoke layer **345** and the upper yoke layer **340**, and has a spiral structure with a back contact portion **3402** as a center. The write coil layer **343** is formed of a conductive material such as Cu (copper). The write coil layer **343** is covered with a coil-insulating layer **344** that is formed of an insulating material such as a heat-cured photoresist and electrically isolates the write coil layer **343** from the upper yoke layer **340**. The write coil layer **343** has a monolayer structure in the present embodiment; however, may have a two or more layered structure or a helical coil shape. Further, the number of turns of the write coil layer **343** is not limited to that shown in FIG. **4**, and may be, for example, in the range from two to seven.

The back contact portion **3402** has a though-hole extending in X-axis direction, and the waveguide **35** and insulating layers that covers the waveguide **35** pass through the though-hole. In the though-hole, the waveguide **35** is away at a predetermined distance of, for example, at least 1 μm from the inner wall of the back contact portion **3402**. The distance prevents the absorption of the waveguide light by the back contact portion **3402**.

The lower yoke layer **345** is formed on an insulating layer **383** made of an insulating material such as Al_2O_3 (alumina), and acts as a magnetic path for the magnetic flux returning from a soft-magnetic under layer that is provided under the magnetic recording layer (perpendicular magnetization layer) of the magnetic disk. The lower yoke layer **345** is formed of a soft-magnetic material, and its thickness is, for example, approximately 0.5 to 5 μm. Further, the lower shield **3450** is a part of the magnetic path, being connected with the lower yoke layer **345** and reaching the head end surface **2210**. The lower shield **3450** is opposed to the main magnetic pole **3400** through the surface plasmon generator **36**, and acts for receiving the magnetic flux spreading from the main magnetic pole **3400**. The lower shield **3450** has a width in the track width direction greatly larger than that of the main magnetic pole **3400**. This lower shield **3450** causes the magnetic field gradient between the end portion of the lower shield **3450** and the first main pole portion **3400*a*** to become steeper. As a result; jitter of signal output becomes smaller, and therefore, error rates during read operations can be reduced. The lower shield **3450** is preferably formed of a material with high saturation magnetic flux density such as NiFe (Permalloy) or an iron alloy as the main magnetic pole **3400** is formed of.

Further, also as shown in FIG. **5**, an inter-element shield layer **39** is preferably provided between the MR element **33** and the electromagnetic transducer **34** (lower yoke layer **345**), sandwiched by the insulating layers **382** and **383**. The inter-element shield layer **39** plays a role for shielding the MR element **33** from the magnetic field generated from the electromagnetic transducer **34**, and may be formed of a soft-magnetic material. Here, the above-described insulating layers **381**, **382**, **383**, **384**, **385** and **386** constitute the overcoat layer **38**.

Referring also to FIG. **4**, laser light **53*a***, the spot size of which the spot-size converter **43** changes (reduces), enters the waveguide **35** from the light-receiving end surface **352**, and propagates through the waveguide **35**. The waveguide **35** extends from the light-receiving end surface **352** to the end surface **350** on the head end surface **2210** side through the through-hole that is provided in the back contact portion **3402** and extends in X-axis direction. Furthermore, the surface plasmon generator **36** is a near-field optical device that transforms the laser light (waveguide light) propagating through the waveguide **35** into near-field light. A part on the head end surface **2210** side of the waveguide **35** and the surface plasmon generator **36** are provided between the lower shield **3450** (lower yoke layer **345**) and the main magnetic pole **3400** (upper yoke layer **340**). Further, a portion of the upper surface (side surface) of the waveguide **35** on the head end surface **2210** side is opposed to a portion of the lower surface (including a propagation edge **360** (FIG. **5**)) of the surface plasmon antenna **36** with a predetermined distance. The sandwiched portion between these portions constitutes a buffering portion **50** having a refractive index lower than that of the waveguide **35**. The buffering portion **50** acts for coupling the laser light (waveguide light) that propagates through the waveguide **35** with the surface plasmon generator **36** in a surface plasmon mode. A detailed explanation of the waveguide **35**, the buffering portion **50** and the surface plasmon generator **36** will be given later with reference to FIG. **5**.

As also shown in FIG. **4**, a marker layer **11** is provided on the head end surface **2211** side. The marker layer **11** is made of a metal such as Au (gold), Cu (copper) or NiFe that reflects alignment light **70** (FIG. **3**) used in the "semi-active alignment" according to the present invention, which will be detailed later. An end surface of the marker layer **11** exposed in the head end surface **2211** acts as the marker **110**. The marker layer **11** is provided above the element-integration surface **2202** of the slider substrate **220** and is at a predetermined distance D_{MK} from the spot-size converter **43** (optical system **31**) in the direction perpendicular to the element-integration surface **2202** (Z-axis direction). The distance D_{MK} is the distance between the center **4300** of the light-receiving end surface **430** and the center **1100** of the marker **110** in Z-axis direction. The distance D_{MK} is determined by the thicknesses of the spot-size converter **43** and the marker layer **11** and the thickness of a portion of the overcoat layer sandwiched between the spot-size converter **43** and the marker layer **11**. These thicknesses are controlled with an ultrahigh accuracy within ±±50 nm or less, achieved by thin-film formation technology. Consequently, the distance D_{MK}, that is, the position of the marker **110** with respect to the light-receiving end surface **430** can be set with an ultrahigh accuracy.

The thickness T_{MK} of the marker layer **11** is equivalent to the width of the marker **110** in Z-axis direction. The width of the marker **110** is set to 0.3 μm, for example, so that the marker **110** can be identified under a microscope during alignment, or a sufficient amount of alignment light is reflected by the marker **110**. While the marker layer **11** in FIG. **4** is provided on the trailing side (+Z side) of the spot-size converter **43** (optical system **31**), the marker layer **11** may be provided on the leading side (−Z side).

FIG. **5** shows a perspective view schematically illustrating the configuration of the waveguide **35**, the surface plasmon generator **36** and the main magnetic pole **3400**. In the figure, the head end surface **2210** is positioned at the left side, the surface **2210** including positions where write field and near-field light are emitted toward the magnetic recording medium.

As shown in FIG. **5**, the configuration includes the waveguide **35** for propagating laser light (waveguide light) **53***b* used for generating near-field light toward the end surface **350**, and the surface plasmon generator **36** that has a propagation edge **360** as an edge on which surface plasmon excited by the laser light (waveguide light) **53***b* propagates. The surface plasmon generator **36** further includes a near-field light generating end surface **36***a* that reaches the head end surface **2210** and is a destination for the excited surface plasmon. Further, a buffering portion **50** is a portion sandwiched between a portion of the side surface **354** of the waveguide **35** and a portion of the lower surface **362** including the propagation edge **360** of the surface plasmon generator **36**. That is, a portion of the propagation edge **360** is covered with the buffering portion **50**. The buffering portion **50** acts for coupling the waveguide light **53***b* with the surface plasmon generator **36** in a surface plasmon mode. Further, the propagation edge **360** plays a role of propagating the surface plasmon excited by the waveguide light **53***b* to the near-field light generating end surface **36***a*. Here, side surfaces of the waveguide **35** are defined as, out of end surfaces surrounding the waveguide **35**, end surfaces other than the end surface **350** on the head end surface **2210** side and the light-receiving end surface **352** on the opposite side. These side surfaces serve as surfaces on which the propagating waveguide light **53***b* can be totally reflected in the waveguide **35** that corresponds to a core. In the present embodiment, the side surface **354** of the waveguide **35**, a portion of which is in surface contact with the buffering portion **50**, is the upper surface of the waveguide **35**. And, the buffering portion **50** may be a portion of the overcoat layer **38** (FIG. **2**), or may be provided as a new layer other than the overcoat layer **38**.

Specifically, the waveguide light **53***b*, which has advanced to near the buffering portion **50**, is involved with the optical configuration including the waveguide **35** with a refractive index n_{WG}, the buffering portion **50** with a refractive index n_{BF} and the surface plasmon generator **36** made of a metal, and induces a surface plasmon mode on the propagation edge **360** of the surface plasmon generator **36**. That is, the waveguide light couples with the surface plasmon generator **36** in a surface plasmon mode. The induction of the surface plasmon mode becomes possible by setting the refractive index n_{BF} of the buffering portion **50** to be smaller than the index n_{WG} of the waveguide **35** ($n_{BF}<n_{WG}$). Actually, evanescent light is excited within the buffering portion **50** under an optical boundary condition between the waveguide **35** as a core and the buffering portion **50**. Then, the evanescent light couples with the fluctuation of electric charge excited on the metal surface (propagation edge **360**) of the surface plasmon generator **36**, and induces the surface plasmon mode, thereby there is excited surface plasmon **60**. To be exact, there excited is surface plasmon polariton in this system because surface plasmon as elementary excitation is coupled with an electromagnetic wave. However, the surface plasmon polariton will be hereinafter referred to as surface plasmon for short. The propagation edge **360** is located closest to the waveguide **35** on the inclined lower surface **362** of the surface plasmon generator **36**, and is just an edge where electric field tends to converge; thus surface plasmon can easily be excited on the edge **360**.

In the light source and optical system as shown in FIGS. **2**, **4** and **5**, the laser light emitted from the light-emission center **4000** of the laser diode **40** preferably has TM-mode polarization in which the oscillation direction of electric field of the laser light is along Z-axis. Further, the waveguide light **53***b* accordingly have a linear polarization in which the oscillation direction of electric field of the laser light is Z-axis direction, that is, perpendicular to the layer surface of the waveguide **35**. Setting the polarization enables the waveguide light **53***b* propagating through the waveguide **35** to be coupled with the surface plasmon generator **36** in a surface plasmon mode.

Further, as shown in FIG. **5**, the near-field light generating end surface **36***a* of the surface plasmon generator **36** is located close to the end surface **3400***e* of the main magnetic pole **3400** reaching the head end surface **2210**, and is positioned on the leading side (−Z side) of the end surface **3400***e* and on the trailing side (+side) of the lower shield **3450**. The distance between the near-field light generating end surface **36***a* and the end surface **3400***e* is preferably set to be a sufficiently small value of, for example, 100 nm or less. In the thermally-assisted magnetic recording, the near-field light generating end surface **36***a* functions as a main heating action part, and the end surface **3400***e* functions as a writing action part. Therefore, by setting the distance as described above, write field with a sufficiently large gradient can be applied to a portion of the magnetic recording layer of the magnetic disk, the portion having been sufficiently heated.

The propagation edge **360** extends to the near-field light generating end surface **36***a*. Further, in the present embodiment, a portion of the propagation edge **360** on the end surface **36***a* side (on the head end surface **2210** side) has a shape of straight line or curved line extending so as to become closer to the end surface **361** of the surface plasmon generator **36** as going toward the near-field light generating end surface **36***a*, the end surface **361** being opposite to the propagation edge **360**. Surface plasmon **60** excited on the propagation edge **360** propagates on the propagation edge **360** along the direction shown by arrows **61**. The propagation edge **360** is made rounded to prevent surface plasmon from running off from the edge **360**, and thus to prevent the degradation of light use efficiency.

The near-field light generating end surface **36***a* of the surface plasmon generator **36**, in the present embodiment, has an isosceles triangle shape in which one apex on the leading side (−Z side) is the end of the propagation edge **360**. Thus, surface plasmon **60** propagating on the propagation edge **360** reaches the near-field light generating end surface **36***a* having an apex **360***a* as a destination of the edge **360**. As a result, the surface plasmon **60**, namely, electric field converges in the near-field light generating end surface **36***a*. Thereby near-field light **62** is emitted from the end surface **36***a* toward the magnetic recording layer of the magnetic disk **10**, and reaches the surface of the magnetic disk **10** to heat a portion of the magnetic recording layer of the disk **10**. This heating reduces the anisotropic magnetic field (coercive force) of the portion to a value with which write operation can be performed. Immediately after the heating, write field **63** generated from the main magnetic pole **3400** is applied to the portion to perform write operation. Thus, the thermally-assisted magnetic recording can be accomplished.

Further, in the present embodiment, the waveguide **35** has a cross-section taken by YZ-plane of a rectangular or trapezoidal shape. The width W_{WG} in the track width direction (Y-axis direction) of a portion of the waveguide **35** near the end surface **350** on the head end surface **2210** side may be, for example, in the range approximately from 0.3 to 0.7 μm. Further, the thickness T_{WG} (in Z-axis direction) of the waveguide **35** may be, for example, in the range approximately from 0.3 to 0.7 μm.

Further, the side surfaces of the waveguide **35**: the upper surface **354**, the lower surface **353**, and both the side surfaces **351** in the track width direction (Y-axis direction) have a surface contact with the overcoat layer **38** (FIG. **2**), that is, the insulating layers **384** and **385** (FIG. **4**), except a portion having a surface contact with the buffering portion **50**. Here, the waveguide **35** is formed of a material with a refractive index n_{WG} higher than the refractive index n_{OC} of the constituent material of the overcoat layer **38**, made by using, for example, a sputtering method. For example, in the case that the wavelength λ_L of the laser light is 600 nm and the overcoat layer **38** is formed of Al_2O_3 (n=1.63), the waveguide **35** can be formed of, for example, SIO_XN_Y (n=1.7–1.85), Ta_2O_5 (n=2.16), Nb_2O_5 (n=2.33), TiO (n=2.3–2.55) or TiO_2 (n=2.3–2.55). The just-described material structure of the waveguide **35** enables the propagation loss of laser light **53***b* to be reduced due to the excellent optical characteristics of the constituent material. Further, the waveguide **35** that acts as a core can provide the total reflection in all the side surfaces of the waveguide **35** due to the existence of the overcoat layer **38** acting as a clad. As a result, more amount of laser light **53***b* can reach the position of the buffering portion **50**, which improves the propagation efficiency of the waveguide **35**.

The surface plasmon generator **36** is preferably formed of a conductive material of, for example, a metal such as Ag, Au, pd, Pt, Rh, Ir, Ru, Cu or Al, or an alloy made of at least two of these elements, especially an alloy with Ag as a main component. Further, the surface plasmon generator **36** can have a width W_{NF} in the track width direction (Y-axis direction) of the upper surface **361**, the width W_{NF} being sufficiently smaller than the wavelength of the laser light **53***b*, and being in the range of, for example, approximately 10 to 100 nm. And the surface plasmon generator **36** can have a thickness T_{NF1} (in Z-axis direction) sufficiently smaller than the wavelength of the laser light **53***b*, the thickness T_{NF1} being in the range of, for example, approximately 10 to 100 nm. Further, the length (height) H_{NF} (in X-axis direction) can be set to be in the range of, for example, approximately 0.8 to 6.0 μm.

The buffering portion **50** is formed of a dielectric material having a refractive index n_{BF} lower than the refractive index n_{WG} of the waveguide **35**. For example, when the wavelength λ_L of the laser light is 600 nm and the waveguide **35** is formed of Ta_2O_5 (n=2.16), the buffering portion **50** can be formed of SiO_2 (n=1.46) or Al_2O_3 (n=1.63). Further, the length L_{BF} (in X-axis direction) of the buffering portion **50**, namely, the length of a portion sandwiched between the side surface **354** of the waveguide **35** and the propagation edge **360**, is preferably in the range of 0.5 to 5 μm, and is preferably larger than the wavelength λ of the laser light **53***b*. Further, the thickness T_{BF} (in Z-axis direction) of the buffering portion **50** is preferably in the range of 10 to 200 nm.

The optical system that is provided in the head element part **221** and generates light for thermal assist is not limited to the above-described one. For example, as an alternative, the laser light generated from the laser diode **40** may be emitted directly from the end surface **350** of the waveguide **35** that reaches the head end surface **2210**, instead of providing the surface plasmon generator **36** for generating near-field light. The emitted light could heat the magnetic recording layer of the magnetic disk to perform thermal assist. As another alternative, a plasmon antenna made of a metal piece may be provided at the end surface **350** of the waveguide **35** that reaches the head end surface **2210**. The plasmon antenna may be irradiated with the waveguide light propagating through the waveguide **35**; thus near-field light could be emitted toward the magnetic disk.

FIGS. **6***a* to **6***c* show schematic views illustrating one embodiment of a method for manufacturing the thermally-assisted magnetic recording head **21** using the semi-active alignment according to the present invention.

As illustrated in FIG. **6***a*, the thermally-assisted magnetic recording head **21** according to the present invention is fabricated by joining and bonding a light source unit **23** and a slider **22** with each other. During the fabrication, the relative positions of the slider **22** and the light source unit **23** are determined in such a way that laser light emitted from the light-emission center **4000** located in the light-emitting surface **400** of the laser diode **40** is most incident at the light-receiving end surface **430** provided in the end surface **2211** of the head element part **221**.

According to the embodiment shown in FIG. **6***a*, first the light source unit **23** and the slider **22** are attached to an alignment apparatus **74** (FIG. **6***b***1**) which adjusts the relative positions of the light source unit **23** and the slider **22**. Then, the bonding surface **2300** of the unit substrate **230** and the back surface **2201** of the slider substrate **220** are opposed to each other, and an alignment light source **71** is used to irradiate a rear light-emission center **4001** of the laser diode **40** with alignment light **70** to cause the alignment light **70** to enter the laser diode **40**. The alignment light **70** may be a laser light or a monochromatic light which have a wavelength λ_{ALM} that passes through the semiconductor material of the laser diode **40**, or a light having a wavelength band including the wavelength λ_{ALM}. If the laser diode **40** is a GaAs-type laser diode, the wavelength λ_{ALM} can be set to a value in the near-infrared band, for example 820 nm. The alignment light source **71** may be a laser diode or an electric lamp. The alignment light **70** that has entered the laser diode **40** passes through the laser diode **40** and is emitted from the light-emission center **4000**.

Then, a multi-field-of-view microscope such as a dual-field-of-view camera **72** is inserted between the light source unit **23** and the slider **22**. For allowing the insertion, the distance between the bonding surface **2300** (the first unit electrode **450**) of the unit substrate **230** and the back surface **2201** (the back surface electrode **4100**) of the slider substrate **220** is set to a value in the range of, for example, approximately 10 to 20 cm before or after the alignment light **70** is entered into the laser diode **40**. The multi-field-of-view microscope captures the alignment light **70** emitted from the light-emission center **4000** and the light-receiving end surface **430** or the marker **110** which is in a predetermined positional relation with the light-receiving end surface **430**, in different fields of view to enable the positional relation between the light-emission center **4000** and the light-receiving end surface **430** to be observed. In particular, the dual-field-of-view camera **72** includes two objective lenses **720** and **721** on its upper surface which faces the light-emission center **4000** and on its lower surface which faces the light-receiving end surface **430**, respectively. The optical axes of the objective lenses **720** and **721** are in a predetermined positional relation with each other (they coincide with each other in the embodiment shown in FIG. **6***a*). An image of the light-emission center **4000** (alignment light **70**) and an image of the light-receiving end surface **430** (marker **110**) captured by the objective lenses **720** and **721** are transmitted through an optical system including components such as prisms and imaging lenses, are received at image pickup devices **722** and **723**, respectively, and are converted to electrical signals. The image pickup devices **722** and **723** may be image pickup tubes or solid-state image pickup devices such as CCDs. The electrical signals converted from the images are sent to an image recognition system **73**. The image recognition system **73** recognizes the images and enables the alignment apparatus **74** to adjust the positions of the light source unit **23** and the slider **22** on the basis the recognized images so that the light source unit **23** and the slider **22** are positioned in a desired positional relation with each other.

Here, an implementation will be described below in which the dual-field-of-view camera **72** including objective lenses **720** and **721** with a common optical axis OX is used to recognize alignment light **70** emitted from the light-emission center **4000** and the light-receiving end surface **430** as shown in FIG. **6***b***1**. First, the dual-field-of-view camera **72** is used to recognize an image of the alignment light **70** and an image of the light-receiving end surface **430**. Then, the light source unit **23** and the slider **22** are moved relative to each other in YZ plane until the images coincide with each other. When the images coincide with each other, the light-emission center **4000** and the center **4300** of the light-receiving end surface **430** are on the common optical axis OX of the objective lenses **720** and **721**. The two-field-of-view camera **72** is then retracted from between the light source unit **23** and the slider **22**. Then the distance between the light source unit **23** and the slider **22** in X-axis direction is reduced without changing their relative positions in YZ plane until the light source unit **23** and the slider **22** come into contact with each other, thereby determining their relative positions.

An alternative of the alignment shown in FIG. **6***b***1** will be described in which the dual-field-of-view camera **72** including objective lenses **720** and **721** with a common optical axis OX is used to recognize alignment light **70** emitted from the light-emission center **4000** and a marker **110** that is in a predetermined positional relation with the light-receiving end surface **430**. First, the dual-field-of-view camera **72** recognizes an image of the alignment light **70** and an image of the marker **110**. Then, the light source unit **23** and the slider **22** are moved relative to each other in Y-Z plane until the images coincide with each other. When the images coincide with each other, the light-emission center **4000** and the center **1100** of the marker **110** are on the common optical axis OX of the objective lenses **720** and **721**. The light source unit **23** and the slider **22** are then further moved relative to each other by a predetermined amount in YZ plane. The predetermined amount and the direction of the movement are the distance between the center **4300** of the light-receiving end surface **430** and the center **1100** of the marker **110** and the direction from the center **1100** to the center **4300**, respectively. For example, in the embodiment illustrated in FIG. **2**, the light source unit **23** is moved in −Z direction by the distance D_{MK} with respective to the slider **22** (as indicated by arrow **75** in FIG. **6***b***2**). Then, the dual-field-of-view camera **72** is retracted from between the light source unit **23** and the slider **22**. Then the distance between the light source unit **23** and the slider **22** in X-axis direction is reduced without changing their relative positions in YZ plane until the light source unit **23** and the slider **22** come into contact with each other, thereby determining their relative positions.

Lastly, the light source unit **23** and the slider **22** in contact with each other are bonded together as shown in FIG. **6***c*. Here, an example will be described in which a conductive resin is used for the bonding. A conductive UV curable resin such as UV curable epoxy resin or UV curable acrylic resin with an added conductive filler is applied to the surface of the first unit electrode **450** of the light source unit **23** beforehand. Here, the conductive UV curable resin may also be applied to the surface of the back surface electrode **4100** of the slider **22** beforehand. Alternatively, the conductive UV curable resin may be applied only on the surface of the back surface electrode **4100**. The light source unit **23** and the slider **22** are then brought into contact with each other and, with the first unit electrode **450** and the back surface electrode **4100** being joined together, the conductive UV curable resin at the interface is irradiated with UV light **76** to cure the conductive UV curable resin to bond the light source unit **23** and the slider **23** together. With this, a thermally-assisted magnetic recording head **21** is completed.

In an alternative of the bonding, the light source unit **23** and the slider **22** may be bonded by soldering using one of lead-free solders such as Au—Sn alloy, instead of using a conductive UV curable resin. In that case, an evaporated film of Au—Sn alloy is deposited on the surface of the first unit electrode **450** or the surface of the back surface electrode **4100** or both to a thickness in the range of approximately 0.7 to 1 μm, for example. Then the light source unit **23** and the slider **22** are brought into contact with each other and, with the first unit electrode **450** and the back surface electrode **4100** being joined together, heating is performed with a hotplate or the like under a hot-air blower to approximately 200 to 300° C. to bond the light source unit **23** onto the slider **22**. Instead of bonding using a conductive resin or solder described above, Au—Au ultrasonic joining may be used to bond the light source unit **23** and the slider **22**. If neither the light source unit **23** nor the slider **22** has electrodes at the bonding areas, a non-conductive UV curable resin can be applied to the bonding surface **2300** and/or the back surface **2201** to bond the light source unit **23** and the slider **22**.

FIGS. **7***a* to **7***c* show schematic views illustrating another embodiment of a method for manufacturing the thermally-assisted magnetic recording head **21** using the semi-active alignment according to the present invention.

According to the embodiment illustrated in FIG. **7***a*, first a light source unit **23** and a slider **22** are attached to an alignment apparatus **84** (FIG. **7***b*) which adjusts the relative positions of the light source unit **23** and the slider **22**. Then, the bonding surface **2300** of the unit substrate **230** and the back surface **2201** of the slider substrate **220** are opposed to each other and an alignment light source **71** is used to irradiate a rear light-emission center **4001** of the laser diode **40** with alignment light **70** to cause the alignment light **70** to enter the laser diode **40**. The alignment light **70** that has entered the laser diode **40** is transmitted through the laser diode **40** and then emitted from the light-emission center **4000**. The distance between the light-emitting surface **400** of the laser diode **40** and the head end surface **2211** (back surface **2201**) is preferably set to a value between or equal to 2 μm and 20 μm before or after the alignment light **70** is entered in the laser diode **40**. By setting the distance to such a sufficiently small value, the alignment light **70** emitted from the light-emission center **4000** and reflected back from the marker **110** can more reliably reenter the laser diode **40** from the light-emission center **4000**.

Then, as shown in FIG. 7*b*, an alignment camera **82** for observing the element-integration surface **2202** at the front is used to recognize an image of the ridge structure including grooves **55** in the upper surface of the laser diode **40** and images of additional markers **120** and **121**. Then, the light source unit **23** and the slider **22** are moved relative to each other in Y-axis direction until the images are placed in a predetermined positional relation with each other in the track width direction (Y-axis direction). In the embodiment illustrated in FIG. 7*b*, the center line of the ridge structure along X-axis direction and the center lines of the additional markers **120** and **121** along X-axis direction are aligned with each other in Y-axis direction.

The light source unit **23** and the slider **22** are then moved relative to each other in Z-axis direction in such a way that the alignment light **70** emitted from the light-emission center **4000** is reflected back from the marker **110** as reflected light **85**, reenters the laser diode **40** from the light-emission center **4000**, passes through the laser diode **40** and is emitted from the rear light-emission center **4001**. The light source unit **23** and the slider **22** are moved relative to each other in Z-axis direction until the intensity of the reflected light **85** emitted from the rear light-emission center **4001** reaches the maximum value, then the movement is stopped. The relative positions of the light-emission center **4000** and the center **4300** of the light-receiving end surface **430** at the time the movement has been stopped is set as the reference positions for alignment in Z-axis direction. A beam splitter **86** such as a combination of a half mirror and a prism is provided between the alignment light source **71** and the rear light-emission center **4001** (the laser diode **40**) to enable the reflected light **85** emitted from the rear light-emission center **4001** after passing through the laser diode **40** to be detected at a photo-detector **87** such as a photodiode to monitor the intensity of the reflected light **85**.

Then, the light source unit **23** and the slider **22** are further moved relative to each other by a predetermined distance in YZ plane from the alignment reference positions described above. The predetermined distance and the direction of the movement are the distance between the center **4300** of the light-receiving end surface **430** and the center **1100** of the marker **110** and the direction from the center **1100** to the center **4300**, respectively. For example, in the embodiment shown in FIG. **2**, the light source unit **23** is moved in −Z direction by the distance D_{MK} with respective to the slider **22** (as indicated by arrow **88** shown in FIG. 7*b*). Then, the distance between the light source unit **23** and the slider **22** in X-axis direction is reduced until they come into contact with each other without changing their relative positions in YZ plane, thereby determining their relative positions.

Lastly, the light source unit **23** and the slider **22** in contact with each other are bonded together as illustrated in FIG. 7*c*. For the bonding, a UV curable resin such as a conductive UV curable resin (in conjunction with irradiation with UV light **89**), soldering, or Au—Au ultrasonic joining can be used as described with respect to the embodiment shown in FIG. 6*c*. With the bonding, a thermally-assisted magnetic recording head **21** is completed.

Since the manufacturing methods described with respect to FIGS. 6*a* to 6*c* and FIGS. 7*a* to 7*c* use "semi-active alignment" that uses alignment light **70** to align the light source unit **23** and the slider **22** with each other, the alignment can be accomplished with a sufficiently high alignment accuracy, for example an accuracy within ±0.5 μm or a higher accuracy in a short processing time. In practice, the "semi-active alignment" according to the present invention does not require power supply probes to be applied to the electrodes of the light source. Therefore, the time required for alignment is reduced compared with conventional active alignment. Furthermore, since no head structure or proving facilities for probing are required, the manufacturing load can be kept low. In addition, in the "semi-active alignment" according to the present invention, the light-emission center of the light source can be directly recognized without having to rely on any marker, a high alignment accuracy can be achieved compared with the conventional passive alignment. Further, since a marker does not need to be added to the light-emitting surface of the light source, an increase of cost in provision of the light source can be avoided.

All the foregoing embodiments are by way of example of the present invention only and not intended to be limiting, and many widely different alternations and modifications of the present invention may be constructed without departing from the spirit and scope of the present invention. Accordingly, the present invention is limited only as defined in the following claims and equivalents thereto.

The invention claimed is:

1. A method for manufacturing a thermally-assisted magnetic recording head in which a light source unit and a slider are joined to each other, the light source unit including a light source that is provided in a source-installation surface adjacent to a bonding surface of a unit substrate and has a light emitting surface including a light-emission center adjacent to the bonding surface, the slider including an optical system that is provided on an element-integration surface adjacent to an opposed-to-medium surface of a slider substrate and has a light-receiving end surface reaching a back surface opposite to the opposed-to-medium surface of the slider substrate, the manufacturing method comprising the steps of:

causing a light emitted from an alignment light source to enter the light source from a surface opposite to the light emitting surface including the light-emission center of the light source while the bonding surface of the light source unit is opposed to the back surface of the slider substrate, the alignment light source being provided separately from the light source unit and being different from the light source;

detecting the light that has passed through the light source and is emitted from the light-emission center to align the light-emission center of the light source unit with the light-receiving end surface of the slider; and

bonding the light source unit to the slider in such a way that the bonding surface of the unit substrate and the back surface face each other.

2. The manufacturing method as claimed in claim **1**, wherein:

a multi-field-of-view microscope is inserted between the bonding surface of the light source unit and the back surface of the slider substrate; and

an alignment of the light-receiving end surface and the light-emission center is performed by using the multi-field-of-view microscope in such a way that the light-receiving end surface or a marker that is in a predetermined positional relation with the light-receiving end surface is captured by a different field of view from a field of view that captures a light emitted from the light-emission center.

3. The manufacturing method as claimed in claim **2**, wherein a dual-field-of-view microscope is used as the multi-field-of-view microscope, which comprises two objective lenses in respective upper and lower surfaces of the microscope, optical axes of the two objective lenses being in a predetermined positional relation with each other.

4. The manufacturing method as claimed in claim 1, wherein the light source unit and the slider are moved relative to each other from reference positions by a predetermined amount to align the light source unit and the slider with each other, the reference positions being positions in which the light-emission center and the light-receiving end surface are located when the light emitted from the light-emission center, reflected by a marker, reentering the light source, and then passing through the light source, is emitted from the surface opposite to the light emitting surface including the light-emission center, the marker being provided on the back surface of the slider substrate and being in a predetermined positional relation with the light-receiving end surface.

5. The manufacturing method as claimed in claim 4, wherein the alignment of the light source unit and the slider is performed using the reference positions in which the light-emission center and the light-receiving end surface are located when an intensity of the light that reenters the light source and is emitted from the surface opposite to the light emitting surface including the light-emission center becomes maximum.

6. The manufacturing method as claimed in claim 4, wherein a marker layer made of a material that reflects the light is formed at a position above the element-integration surface of the slider substrate and apart from the optical system with a predetermined distance in a direction perpendicular to the element-integration surface, and an end surface of the marker layer is used as the marker, the end surface reaching the back surface.

7. The manufacturing method as claimed in claim 4, wherein an alignment in a track width direction of the light source and the light-receiving end surface is performed by using an additional marker that is provided in the element-integration surface of the slider substrate and is in a predetermined positional relation with the light-receiving end surface in the track width direction.

8. The manufacturing method as claimed in claim 4, wherein a distance between the surface including the light-emission center of the light source and the back surface is set to be 2 micrometers or more and to be 20 micrometers or less when aligning the light-emission center of the light source unit and the light-receiving end surface of the slider with each other.

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